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THE MERCURY MINERALS FROM TERLINGUA, TEXAS

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THE MERCURY MINERALS FROM TERLINGUA, TEXAS.

By W. F. HILLEBRAND and W. T. SCHALLER.[a]

INTRODUCTION.

In the late fall of 1905 the senior author received for identification from Mr. H. W. Turner, at that time connected with the Marfa and Mariposa Mining Company, of Terlingua, Tex., specimens of two minerals from the well-known Terlingua mercury field in Brewster County. One of these proved to be the unidentified mineral referred to as No. 5 by A. J. Moses in his paper[b] on new mercury minerals from this district, namely, terlinguaite, eglestonite, and montroydite, the last of these being mercuric oxide, the others oxychlorides. The composition of Mr. Turner's specimens of this No. 5 proved to be so remarkable, in showing that the mineral belonged to the mercury-ammonium compounds hitherto unknown in nature, that more material was solicited, not only of No. 5, but also of the minerals described more fully by Moses, in order to subject these last to more detailed examination as to their oxygen content. This had been determined solely by difference in the analyses reported by him, and, in the light of the unexpected composition of No. 5, the remainder assumed to be oxygen might not have been wholly such. The result, however, of this examination was to confirm the results published by Moses.

Mr. Turner kindly placed us in correspondence with Mr. J. H. Hartley, also in the employ of the Marfa and Mariposa Mining Company, who during the next few months furnished much excellent material, comprising all the above-indicated species, besides calomel and mercury. Later an additional supply of No. 5 was sent by Mr. R. M. Wilke, of Berkeley, Cal., who had earlier received his material from Mr. Hartley. Prof. A. J. Moses kindly identified the new mineral with his No. 5, and sent his original measurements of it. To all these gentlemen our thanks are tendered, especially to Mr. Hartley for his open-handed liberality and for the information conveyed by some of his letters. To Dr. P. G. Nutting, of the Bureau of Standards, Washington, D. C., and Prof. B. B. Boltwood, of Yale Univer-

[a] Chemistry by Hillebrand and crystallography by Schaller.
[b] Am. Jour. Sci., 4th ser., vol. 16, 1903, p. 253.

sity, we are also under obligations for tests on this mineral No. 5, which in the following pages will be referred to by the name kleinite.

When this investigation was commenced it was without the slightest anticipation of the magnitude of the work or that such a length of time would elapse before the detailed results could be put in print. In spite of the time consumed at intervals during a year and a half we are well aware that many interesting points have been either not entered on at all or very inadequately studied. This is particularly true with respect to the unique mineral kleinite, partly because the first sendings did not afford sufficient material of selected quality for the completion of the investigations, so that it was necessary to repeat on new samples entire analyses and series of tests that might have been spared if the samples of each mineral had been uniform in quality. Then, again, the importance of certain tests did not become apparent till the test material was exhausted; and furthermore the best available was not suitable for the final settlement of special points.

OCCURRENCE AND ASSOCIATIONS OF THE MINERALS.

GEOLOGIC OCCURRENCE.

No attempt will be made to repeat at length the published descriptions of those who are acquainted at first hand with the geologic occurrence of the mercury minerals in Brewster County, Tex., but a very brief statement seems called for on behalf of those readers who are not familiar with the writings of the geologists who have visited the field.

The mercury ores, chiefly cinnabar, are found in both Upper and Lower Cretaceous formations, but up to the present the productive workings have been in the Lower Cretaceous, which is composed mostly of thick-bedded limestones. The lodes, in Turner's words,[a] "are distinctly of the nature of fissure veins and are mineralized lines of faulting. * * *" According to the composition of the vein matter they are either friction-breccia lodes or calcite lodes. In the Upper Cretaceous the deposits are in fissure veins in the Eagle Ford shale. There the veins are filled with clay and gypsum, and less iron oxides and calcite. The only ores in them are cinnabar and mercury, with which is associated considerable pyrite, a mineral that has disappeared from the veins of the Lower Cretaceous. Quartz is wholly absent from the lodes of both formations. The lodes are much cut by igneous dikes, etc., and the ore deposits are said to be invariably near these manifestations of dynamic activity.

The minerals that form the subject of the present report are from the Lower Cretaceous, and, so far as known to us, came from the

[a] Turner, H. W., The Terlingua quicksilver deposits. Econ. Geology vol. 1 1905-6, p. 265.

properties of the Marfa and Mariposa Mining Company, especially the Terceiro shaft. Although the chief ore of the region is cinnabar, no trace of this shows on any of the specimens sent us,[a] the reddish color of parts of some specimens being due to an oxide of iron. The suspicion is forced upon us by this circumstance and by the writings of geologists and letters from Mr. Hartley that the crystals of montroydite have been more than once mistaken for cinnabar.

No precise information is available as to the underground relations of the present specimens to the cinnabar ore or of the different specimens and lots to each other, but from Mr. Hartley's statements it is evident that these minerals in well-crystallized condition are extremely scarce, and that but few cavities containing them have been opened, though it seems no less true that many tons of material inferior or worthless from the mineralogist's point of view have been run through the furnaces.

In the absence of adequate information on which to base a complete theory to account for the origin and succession of these minerals, it is well to avoid what would be profitless discussion of these points, but it is deemed proper to put before the reader the facts of occurrence and association in so far as they are shown by the specimens at command.

THE MATRIX.

The matrix on which the mercury minerals are deposited is of two kinds: (1) A soft earthy mass, generally of a pink color, and (2) a layer of fairly pure granular calcite. This calcite layer in all our specimens is on the earthy material.

1. The matrix described as a soft earthy mass consists largely of a hydrous siliceous-aluminous material insoluble in hydrochloric acid, stained by iron compounds, and with varying but small amounts of calcium carbonate. It is generally of a pinkish color, rarely white or deep red-brown. When white, it is practically free from calcium carbonate and contains but a trace when red-brown. One of the specimens shows this matrix to have been originally a brecciated limestone cemented together by calcite. Some of the specimens are heavily impregnated with calomel, while others contain a considerable quantity of a yellowish powder, which in one specimen has been qualitatively determined to be kleinite, in others is doubtless terlinguaite, and in still others probably mixtures of terlinguaite and eglestonite (?). All of the specimens of the pinkish matrix that were tested gave a sublimate of calomel in a closed tube, even though no mercury mineral was visible. The white earthy material, which has a clayey appearance and may possibly be somewhat different from the pink, gave no test for carbonates, but did give a sublimate of calomel.

[a] Since the above was written Mr. Turner has sent us some specimens of vermilion cinnabar in a powdery form.

2. The calcite layer or second form of matrix reaches a thickness of about 5 centimeters, but is usually from 2 to 3 centimeters thick. It consists of coarse crystalline calcite, showing large cleavage surfaces, but owing to its compactness showing no crystals except those in a few cavities and large scalenohedral crystals on its surface. The spaces between these last seemed peculiarly suited to the growth of the long needles and other peculiar forms of montroydite that will be described later.

ASSOCIATIONS.

KLEINITE.

Kleinite is found with calcite and gypsum, rarely with barite or calomel. Most of the specimens we have are loose crystals or aggregates of crystals containing only a small amount of the pinkish gangue. The few matrix specimens seen show the kleinite embedded in, impregnating, filling cavities, and crystallized on the pink or mostly light-gray to nearly white earthy matrix that is practically free from carbonates. This clayey material forming the matrix is probably the same as that which is included in the kleinite crystals and which is reported as nonvolatile in the analyses (p. 41). On one specimen received by the Survey (from W. B. Phillips) some years ago from a different locality (working east of California Hill, block G 12) there is a single small mass of kleinite on a large specimen of the pink matrix heavily impregnated with calomel. On no specimen is the kleinite directly associated with either native mercury, mercury oxide, or any mercury oxychloride. Kleinite is found on one specimen, which contains also terlinguaite and montroydite, but, as the following description shows, its association is rather indirect. The specimen consists of a mass of the pink earthy matrix, on which is a calcite layer having on its surface crystals of montroydite and terlinguaite. The pink earthy mass contains considerable kleinite in a massive crystalline state and also as a powder. Thus while the terlinguaite and montroydite are found on the same specimen the matrices are different and the kleinite is further separated from the terlinguaite and montroydite by the intervening calcite layer. Kleinite has not been found included in nor does it inclose any other mineral except invariably some of the clayey gangue.

MONTROYDITE.

Montroydite is found with calcite, terlinguaite, and mercury, and rarely with calomel, gypsum, and eglestonite. It characteristically occurs on the calcite layer with terlinguaite. It is often seen embedded in the calcite, occupying the spaces between the calcite crystals and also deposited on the scalenohedra. The only exception is the specimen showing montroydite with the pink gangue

heavily impregnated with calomel. The montroydite is so associated with terlinguaite and calcite crystals as to suggest very strongly their contemporaneity of formation. One single needle of montroydite was found to which was attached a gypsum crystal. Montroydite has been observed partly inclosed in calcite, and it itself incloses mercury.

TERLINGUAITE.

Terlinguaite has been found with calcite, montroydite, and mercury, and rarely with eglestonite and calomel. The crystallized variety is, with one exception, found only on the calcite layer, while the powdery form occurs on and in the pink matrix. The exception referred to shows terlinguaite (with a little calomel) directly on the pink matrix. Apparently there is no calcite present. The terlinguaite has not been found inclosed in any other mineral except that it is embedded, together with montroydite, in the calcite layer. The crystals of terlinguaite sometimes inclose mercury.

EGLESTONITE.

Eglestonite is found with calomel, calcite, and mercury and rarely with terlinguaite and montroydite. Its characteristic association is with calomel and mercury on the red-brown matrix nearly free from carbonate, the eglestonite itself resting on the calomel. On some of the specimens of terlinguaite on calcite there are a few isolated crystals of eglestonite, but these are always on the terlinguaite. On the specimen of calomel on limestone (Terceiro shaft, No. 5 lode) there are also a few eglestonite crystals on the calcite. Eglestonite is further found inclosed in a massive material composed of calomel and the red-brown phase of the matrix. It has not been found included in or inclosing any other mineral except native mercury, and that only partly.

CALOMEL.

Calomel is associated with native mercury, calcite, and eglestonite, and rarely with kleinite, terlinguaite, and montroydite. Its matrix is characteristically the altered rock of pink or deep red-brown color and carrying only a small amount of carbonates. One small specimen from the Terceiro shaft, No. 5 lode, shows a group of calomel on limestone with calcite crystals, and some specimens of the pink matrix are heavily impregnated with calomel. These last sometimes inclose small pieces of limestone, in the cavities of which is found montroydite. The two specimens which show calomel with kleinite and montroydite, respectively, are free from any native mercury. Calomel has not been found included in or inclosing any other mineral than mercury. It is to be noted that the calomel is found directly on the pink matrix, while eglestonite, calcite, and mercury are found on the calomel.

MERCURY.

Native mercury accompanies all the other mercury minerals, except kleinite. On the pink matrix it is found deposited on calomel and eglestonite, but on the calcite layer it occurs with montroydite and terlinguaite. It is also found inclosed in both of these last.

SUMMARY.

We may thus divide these mercury minerals and their characteristic associates into three groups based on their common occurrence and association. In the first group are kleinite, calcite, and gypsum on a pink to white clayey matrix free from carbonates. In the second group are calomel, eglestonite, mercury, and calcite on the pink matrix. In the third group are montroydite, terlinguaite, and mercury on the calcite layer.

INTRODUCTION TO CRYSTALLOGRAPHY.

The crystallographic work done on these minerals is a striking illustration of the wonderful capabilities of the two-circle goniometer. In order to show this tersely it will here suffice to mention instances. On one-half of an eglestonite crystal, measuring less than one millimeter in diameter, 102 faces were measured and determined. Terlinguaite crystal No. 11, measuring 2 by 1½ by 1¼ millimeters, allowed 96 faces to be measured and determined, and on crystal No. 6, 1¾ by 15 millimeters, 174 faces were determined. While one has generally a good idea of the great simplicity and of the various possibilities of two-circle measurements, it is only during and after the study of a group of minerals such as we have here that one fully realizes what a debt the science of mineralogy owes to Professor Goldschmidt for his development of two-circle measurement. Almost all of the six systems of crystallography are represented by these mercury minerals: Eglestonite, isometric; calomel, tetragonal; kleinite, hexagonal; montroydite, orthorhombic; and terlinguaite, monoclinic; and the phenomenon of twinning is well illustrated by calomel.

Most of the crystals described in this paper are small, being rarely over a few millimeters large. As they all possess a good zone of reference, no difficulty was had in adjusting the crystals in polar position, and rapidly making the necessary measurements. Many of these were repeated, often after a considerable length of time, whenever it seemed advisable to obtain verification of the results first obtained. It was found, as has been observed previously on other minerals, that where the crystals could be accurately adjusted and the faces gave good reflections, the second measurements seldom varied more than two or three minutes from those first obtained.

In his "Development of crystal forms," Goldschmidt [a] has given us a remarkable means of critically analyzing a given form system and showing what forms are most likely to actually occur on a crystal. This furnishes also a most valuable criterion as to whether or not the correct symbols have been deduced from the measurements. Such a discussion of the forms is given in this report for all mercury minerals here described and this has been of the greatest value in deciphering many of the rich combinations observed. The finished discussion does not reveal its value so much to the reader, since the results presented are the final ones obtained after a consideration of all points brought out.

Nothing need be said here relating purely to two-circle goniometric measurements. To those not familiar with the methods reference to any of the recent volumes of the Zeitschrift für Krystallographie und Mineralogie will show many papers by Goldschmidt and others, not only describing the method in its various forms but also eloquently testifying to its value. The different books by Goldschmidt also contain the principles of the method, and to these, together with some particular papers by him, showing the application of the method to crystals of the various systems, the reader who is desirous of acquiring fuller knowledge of this subject is referred.

In order to render the discussion of the forms more intelligible to the reader who has not followed the recent developments along this line, the following short description is given. It may be here mentioned that an excellent summary in English of Goldschmidt's paper on the development of crystal forms is given by A. J. Moses.[b] The paper on "Formulæ and graphic methods for determining crystals in terms of coordinate angles and Miller indices," by Alfred J. Moses and Austin F. Rogers [c] contains much information in a valuable and compact form for the various calculations incidental to two-circle measurement, and the formulæ there given have been used by the writer in preference to the more ponderous ones given by Goldschmidt in the front part of his Winkeltabellen.

In a discussion of the form system of a mineral, it is desirable to reduce each zone under discussion to a form comparable with one of the normal series as previously developed. These normal series are:

$$N_0 = 0 \quad \infty$$
$$N_1 = 0 \quad 1 \quad \infty$$
$$N_2 = 0 \quad \tfrac{1}{2} \quad 1 \quad 2 \quad \infty$$
$$N_3 = 0 \quad \tfrac{1}{3} \quad \tfrac{1}{2} \quad \tfrac{2}{3} \quad 1 \quad \tfrac{3}{2} \quad 2 \quad 3 \quad \infty$$

Etc.

[a] Goldschmidt, V, "Ueber Entwickelung der Krystallformen:" Zeitschr. Kryst. Min., vol. 28, 1897, pp. 1–36, 414–451.

[b] Note on recent mineralogical literature: School of Mines Quart., vol. 25, 1904, p. 415.

[c] School of Mines Quart., vol. 24, 1902, pp. 1–36.

If a zone or zone section of a crystal can be reduced to a form identical with one of the normal series given above, it is probable that that zone or zone section of the crystal is normal and that its growth or formation has suffered little or no disturbance. The individual crystal forms comprising such a normal series have a "probability" of correctness that is greater than the "probability" of forms that do not reduce to a member of the normal series. Therefore, those crystal forms which fail to accord by proper manipulation with some member of the normal series N_n invite criticism to see whether the form really exists or whether the indices have been incorrectly determined. Three results may follow such a criticism of a nonaccording form:

(*a*) The form was determined by an error and does not exist.

(*b*) The indices of the form were incorrectly determined.

(*c*) The determination of the form was correct in every way.

As a result of the last of these (*c*), we must conclude that a part of the crystal zone was affected by disturbing influences during its growth and that, therefore, the particular form was not allowed to grow in its natural position. If, therefore, by a discussion of a zone we produce a series, parts of which do not agree with the normal series, we are not necessarily warranted in casting doubts upon the existence of these nonagreeing forms. But if, by measurements or other means, we offer proof that such forms do exist on the crystal, we may say that the zone has suffered disturbance at that point. In fact, the disturbing influences at work during the formation of a crystal are so numerous and diverse in their effects that it is very seldom that a zone will reduce to a series which, upon comparison with a normal series, shows perfect agreement. This nonagreement with the normal series may take place in three ways:

(*a*) The nonagreeing form may be extra.

(*b*) The nonagreeing form may differ from the corresponding member of the normal series.

(*c*) The form that should agree with a member of the normal series may be missing.

In the discussion in this paper, if a form be extra it is included in the normal series N_n, but is inclosed in parentheses. It is generally ascribed to the effect of "disturbing influences" and criticism of the form leads only to the two questions, (*a*) Does the form actually exist? and (*b*) Is it a vicinal form? If the form differs from the corresponding member of the normal series, it is included in the series N_n but is inclosed in brackets, and generally invites discussion as to the correctness of its indices. When the form to agree with a member of the normal series is missing in the zone under discussion, its absence is indicated in the series N_n by a dot.

The use of these three signs has been introduced by the writer, as he believes that they simplify the discussion and render the comparison of the zone under discussion with the normal series easier.

NONMERCURY MINERALS.

CALCITE.

Calcite is the most abundant of all the minerals found at Terlingua and has been noticed with all of our mercury minerals. Judging from two published papers[a] describing calcite crystals from this region, there are two distinct habits, namely, (1) rhombohedral, due to the large development of the form $f\{02\bar{2}1\}$ and (2) scalenohedral, due to the large development of the common form $v\{21\bar{3}1\}$. All of our crystals are of the latter habit. While the rhombohedral crystals are apparently rather rich in forms, the scalenohedral crystals are very simple, seldom showing any other form than $\{21\bar{3}1\}$. A few crystals have, in addition, $r\{10\bar{1}1\}$ as small faces and $f\{02\bar{2}1\}$ as very narrow dull faces, while one face each of $e\{01\bar{1}2\}$ and $d:\{13.1.\bar{14}.15\}$ were also noticed. A single incomplete crystal measuring 6 millimeters high and 4 millimeters thick showed a somewhat richer combination, namely: $r\{10\bar{1}1\}$, $\epsilon\{01\bar{1}1\}$, $v\{21\bar{3}1\}$, $t\{21\bar{3}4\}$, $\mathfrak{s}\{12\bar{3}2\}$ and the new positive scalenohedron $\mathfrak{h}\{11.5.\bar{16}.21\}$. This crystal is shown in ideal development in figure 1, which, however, does not show the new form $\mathfrak{h}\{11.5.\bar{16}.21\}$ or the form $\mathfrak{s}\{12\bar{3}2\}$. The following table shows the most important of the measured angles.

Measured and calculated angles of calcite.

Form.	Measured.		Calculated.	
	ϕ	ρ	ϕ	ρ
	° ′	° ′	° ′	° ′
$01\bar{1}1$	0 02	44 37	0 00	44 36
$21\bar{3}4$	19 23	33 07	19 06	33 07
$12\bar{3}2$	19 06	51 34	19 06	52 32
$11.5.\bar{16}.21$	17 39	33 43	17 47	33 40
$13.1.\bar{14}.15$	26 20	41 22	26 19	41 39

The negative unit rhombohedron $\epsilon\ \{01\bar{1}1\}$, a rare form, is present as three faces, all very small and giving poor reflections. The new scalenohedron shows only one face, very narrow, not striated, and giving a fair reflection. It is very close to $\{21\bar{3}4\}$ with which it

[a] Eakle, A. S., Notes on lawsonite, columbite, beryl, barite and calcite: Bull. Dept. Geology Univ. California, vol. 5, 1907, p. 91. Sachs, A., Gypsum and calcite crystals from Terlingua, Tex.: Centralbl. Min., Geol. u. Pal., 1907, p. 18.

occurs. The signal is slightly blurred and measurements of the two sides of the signal gave $\phi=17° 25'$ to $17° 53'$; $\rho=33° 42'$ to $33° 44'$. While the indices are rather complex, if we change them to the orientation as given by Goldschmidt (G_2) in his Winkeltabellen, the indices become $\{72\bar{9}7\}$ and the form fits in well between the two known forms $\{21\bar{3}4\}$ and $\{52\bar{7}3\}$.

Symbol $\{52\bar{7}3\}$ becomes $\{62\bar{8}6\}$ G_2.

Symbol $\{11.5.\overline{16}.21\}$ becomes $\{72\bar{9}7\}$ G_2 (new form).

Symbol $\{21\bar{3}4\}$ becomes $\{8.2.\overline{10}.8\}$ G_2.

The following list shows the 29 forms observed on calcite from Terlingua, Tex., with the names of the observers:[a]

Forms noted on calcite from Terlingua, Tex.

$10\bar{1}0$, E., Sa.	$21\bar{3}1$, E., Sa., Sch.	$17.2.\overline{19}.5$, E.
$11\bar{2}3$, E.	$21\bar{3}4$, E., Sch.	$71\bar{8}6$, E.
$10\bar{1}1$, E., Sa., Sch.	$32\bar{5}1$, E.	$51\bar{6}4$, E.
$20\bar{2}1$, E.	$11.5.\overline{16}.21$, Sch.	$41\bar{5}3$, E.
$01\bar{1}2$, E., Sch.	$7.2.\bar{9}.11$, Sa.	$7.4.\overline{11}.3$, E.
$01\bar{1}1$, Sch.	$17.11.\overline{28}.6$, Sa.	$8.5.\overline{13}.3$, E.
$02\bar{2}1$, E., Sa., Sch.	? $16.8.\overline{24}.3$, Sa.	$10.4.\overline{14}.3$, E.
$0.11.\overline{11}.1$, E.	$16.7.\overline{23}.3$, E.	$13.1.\overline{14}.15$, Sch.
$0.13.\overline{13}.1$, Sa.	$52\bar{7}9$, E.	$12\bar{3}2$, Sch.
$0.14.\overline{14}.1$, E.	$41\bar{5}6$, E.	

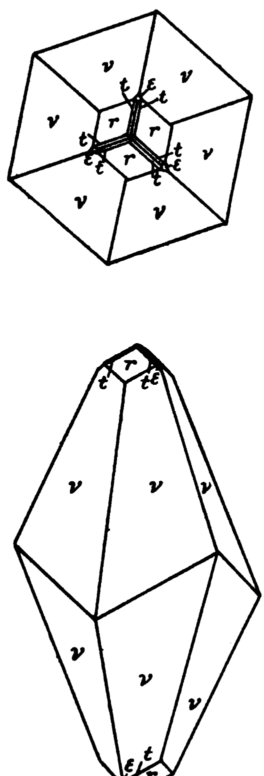


FIGURE 1.—Calcite. Forms, r $\{10\bar{1}1\}$, e $\{01\bar{1}1\}$, v $\{21\bar{3}1\}$, t $\{21\bar{3}4\}$. The new form 𝔥 $\{11.5.\overline{16}.21\}$ is not shown but it lies very near t $\{21\bar{3}4\}$.

The scalenohedral crystals often reach a length of several centimeters and are usually of a brownish shade. This is due to the fact that while the interior is colorless the outside layer of the crystal, several millimeters thick, includes some iron oxides.

GYPSUM.

Gypsum is present on only a few of our specimens, though it occurs rather abundantly with the crystallized kleinite. It has been noticed once on a group of large calcite scalenohedra with montroydite and terlinguaite, and one needle of montroydite was found attached to a mass of gypsum. The abundance of gypsum with the only mercury mineral that contains the SO_4 radicle is noteworthy. It forms small crystal masses, often striated but usually not developed in distinct crystals.[b] On one piece a number of forms were measured in the prism zone on a crystal tabular to the clinopinacoid, with the following results:

[a] E., A. S. Eakle; Sa., A. S. Sachs; Sch., W. T. Schaller.

[b] Since the above was written, long needles of gypsum, elongated parallel to the vertical axis, have been received from Mr. Turner. The largest of these measured 125 by 15 by 8 millimeters.

Measured and calculated angles for gypsum.

Symbol.	Measured.		Calculated.	
	°	′	°	′
$b \wedge m$=010:110	55	42	55	44
$b \wedge r$=010:140	20	33	20	09
$b \wedge h$=010:120	36	48	36	17
$b \wedge a$=010:210	71	04	71	11
$b \wedge z$=010:310	77	11	77	12

The form *l* {111} is also probably present, but too poorly developed to be measured. Sachs[a] has described gypsum crystals from this locality showing {010}, {110}, {111}.

BARITE.

A very few minute barite crystals were found with a lot of loose kleinite crystals received from Mr. Wilke, of Berkeley, Cal. They showed the forms {001}, {011}, and {110}.

Measured and calculated angles for barite.

Symbol.	Measured.		Calculated.	
	°	′	°	′
010∧110	50	44	50	49
001∧011	52	40	52	43

JAROSITE.

A specimen of a brown brecciated rock (not a limestone) was received some years ago from Mr. W. B. Phillips, the accompanying label reading "Vein filling—Sec. 100. Blk. G. 12—Brewster Co., Tex." The relation in place of the specimen to the mercury minerals is not known to us. The fragments of rock are cemented together by a porous brown mass consisting largely of very fine grained compact jarosite. The abundant cavities therein are lined with numerous minute, brilliant, dark-brown crystals of the same mineral. They have a cubic aspect due to the predominance of the *r* faces. Other forms present, usually as very small triangular faces, are *c* {0001} and *s* {02$\bar{2}$1}. The averages of the measured angles are shown below.

Measured and calculated angles for jarosite.

Symbol.	Measured.		Calculated.	
	°	′	°	′
$c \wedge r$ (0001:10$\bar{1}$1)	55	33	55	20
$c \wedge s$ (0001:02$\bar{2}$1)	70	33	70	55
$r \wedge r'$ (10$\bar{1}$1:$\bar{1}$101)	91	36	90	50

[a] Centralbl. Min., Geol., u. Pal., 1907, p. 18.

MERCURY MINERALS.

KLEINITE.

HISTORY.

The senior author announced in the winter of 1905–6[a] the discovery that the yellow mineral from Terlingua, which Moses had thought might be an oxychloride of mercury (his No. 5) related to terlinguaite and eglestonite, was in reality a mercury-ammonium compound containing chlorine and the sulphate radicle, probably with oxygen and possibly with hydrogen. Quantitative data had been obtained, which as to the four main constituents were in close agreement with the values hereinafter submitted, but these were not published for the reason that it was desired to secure confirmatory results on a number of different specimens. Nor was a name for the new mineral offered, because it was intended to give one indicative in a measure of the composition of this unique mineral in case the opinion formed as to its character should be verified. The name that naturally suggested itself was mercurammonite. On the day preceding the appearance of the first of the preliminary announcements (the one in Science) Prof. A. Sachs, of Breslau, offered in a meeting of the Prussian Academy of Sciences a paper[b] on what was evidently the same mineral, but which his analyses showed to be an oxychloride—$Hg_4Cl_2O_3$ or $HgCl_2+3HgO$—and to which he gave the name kleinite, after the eminent mineralogist Carl Klein. His analytical data were:

Sachs's original analyses of kleinite.

	1.	2.	3.	4.
Hg	86.78	82.83	84.26	[a] 87.07
Cl	7.94	7.25	8.02	....
O	[b] 5.28	[c] 4.99	[c] 4.93	....
Residue	....	4.93	[b] 2.79	....
	100.00	100.00	100.00	....

[a] "Absolutely pure material."
[b] Difference.
[c] Calculated for the mercury not required for $HgCl_2$.

The above-mentioned announcement of the mercury-ammonium mineral caused Professor Sachs to make new analyses and to find indeed that his material was of the same nature,[c] but he was disin-

[a] Science, vol. 22, 1905, p. 844; Am. Jour. Sci., 4th ser., vol. 21, 1906, p. 85; Jour. Am. Chem. Soc., vol. 28, 1906, p. 122.
[b] Published Jan. 11, 1906, Sitzungsber. K. preuss. Akad. Wiss., Berlin, 1905, p. 1091.
[c] Centralbl. Min., Geol. u. Pal., 1906, pp. 200–202.

clined to believe that the material first analyzed by him contained any nitrogen or sulphur. His quantitative data were:

Sachs's later analyses of kleinite.

	Sulphur-yellow crystals.		Orange crystals.
Hg	....	....	85.29
Cl	....	....	6.97
SO_3	1.05	0.85	2.57
NH_3	0.44	1.09	2.79

Assuming the greater purity of the sulphur-yellow crystals, he argued from the varying values for sulphur and nitrogen that these could not be integral components of the mineral, and suggested as perhaps plausible the formula $Hg_4(Cl,\frac{1}{2}SO_4)_2[O,(NH_2)_2]_3$, which is of the same type as his oxychloride formula, and from which he deduced the following composition for the three samples tested, the constituents other than nitrogen and sulphur being calculated for the first and second columns, and oxygen and hydrogen (of the NH_2 radicle) in no case directly determined:

Sachs's later analyses recalculated by himself.

	1.	2.	3.
Hg	86.52	86.29	85.29
Cl	6.79	6.96	6.97
SO_4	1.26	1.02	3.09
NH_2	0.41	1.03	2.63
O	5.02	4.70	2.02
	100.00	100.00	100.00

It may be said that the surmises of Professor Sachs have not been verified by the work hereinafter set forth, that the composition of the light-yellow crystals at our disposal does not appear to differ in any essential respect from that of the deep-yellow to orange ones, and that oxygen and hydrogen, if belonging at all to the mineral, are present in such trifling amounts that the composition can not be that assumed by Professor Sachs or even remotely like it.

As to the name, in view of the facts that kleinite has entered into the literature and that no exception can possibly be taken to it other than the above-expressed preference for one more indicative of the nature of the mineral, the senior author waives his right by priority of identification and publication to give it a name in consonance with this feeling, and accepts the name "kleinite."

MODES OF OCCURRENCE.

The various specimens of kleinite may be grouped under three headings, depending on the form of the mineral.

1. Most of the material occurs in distinct crystals rarely over a millimeter in length and usually much less. These came either attached to the white or pinkish, clayey gangue, or more commonly in loose crystals or aggregates of crystals with but a small amount of gangue matter attached. In regard to this separate and loose form, kleinite differs from all the other mercury minerals (except a few large calomel crystals), which are, or at least were originally, attached to a matrix. The crystals vary from equidimensional to prismatic, the various habits being described and illustrated on pages 45 and 46.

2. Sometimes the kleinite is found as a crystalline crust, showing crystal faces but no distinct crystals. This crust, while generally thin, is sometimes of considerable extent, though the total amount of kleinite found in this form is small.

3. One specimen shows the kleinite as a yellow powder impregnating the pink, earthy gangue, and it seems probable that the powdery form also occurs on some of the other specimens, particularly those in which the yellow color of the powder does not change to a different color on exposure to light. In some of these the results of chemical tests would seem to indicate that the powder consists of a mixture of kleinite with some other mineral, though such an association could not be proved to exist.

PHYSICAL PROPERTIES.

COHESION, ETC.

The cleavage of kleinite is basal, good, and prismatic (parallel $m\,\{10\bar{1}0\}$), imperfect. While it is easy to obtain the basal cleavage, the resulting surface is never plane, but always rounded and uneven, and on the goniometer gives a mass of reflections that extend through several degrees. All of these reflections, moreover, are about of the same quality; that is, there are no one or two signals that stand out from the rest. The prismatic cleavage is not always easy to obtain, but can be seen on some of the crystals as natural cleavage faces. The surfaces of these faces are not very smooth and do not have a high polish. This prismatic cleavage was accidentally developed in a basal section by pressing a cleavage piece between two glass plates. Figure 2 shows a diagrammatic sketch of the section. The fracture is uneven. No indication of plasticity or sectility was observed.

The crystals are rather brittle; in fact, it is extremely difficult to prevent thin cleavage pieces from breaking in handling.

The crystals will scratch calcite but not fluorite, though rarely it seemed as if faint lines could be produced on a cleavage surface of fluorite by kleinite. The hardness is therefore about 3.5, probably a little higher.

DENSITY.

Density determinations resulted as follows:

Results of determinations of density of kleinite.

Material and method.	Temperature.	Weight of sample.	Density.
Orange crystals:	° *C.*	*Grams.*	
Penfield's method [a]	23	3.77	7.98
Usual pycnometer method	23	3.77	7.96
Allen's method [b]	25	7.593	7.967
Allen's method [b]	25	7.636	7.99
Allen's method [b]	22	3.016	7.98
Light-yellow crystals:			
Allen's method [b]	22	0.6443	7.94
Allen's method [b]	22	0.6443	7.98
Usual pycnometer method	(?)	0.2928	8.04

[a] Penfield, S. L., Am. Jour. Sci., 3d ser., vol. 50, 1895, p. 448. Also Bull. U. S. Geol. Survey No. 305, 1907, p. 42.

[b] Day, A. L., and Allen, E. T., Pub. Carnegie Inst. No. 31, 1905, p. 55. Am. Jour. Sci., 4th ser., vol. 19, 1905, p. 93. Bull. U. S. Geol. Survey No. 305, 1907, p. 43.

The variations in results for the larger weights are due in part to different degrees of contamination by the earthy gangue, but for the light-yellow crystals are more probably to be ascribed chiefly to the small amount of material available for the tests. The average for the orange crystals is 7.975 and for the light-yellow 7.987, but the results are all low with the possible exception of the value 8.04, because of the attached and included foreign matter. They are, however, much higher than the figure (7.441) given by Sachs, who does not mention the weight of material used or its degree of purity.

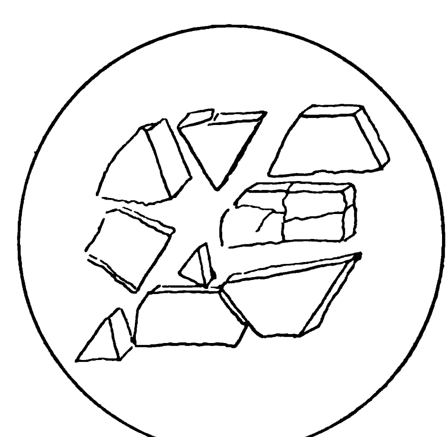


FIGURE 2.—Basal section of kleinite showing the imperfect prismatic cleavage.

LUSTER, COLOR, ETC.

The luster is adamantine to greasy.

Most of our kleinite showed a peculiarity in color at once noteworthy and singular. When exposed to sunlight or even to the dif-

fused light of a room after having been in the dark, the crystals, at first yellow, almost immediately became much deeper in color, generally reddish yellow or orange, but they regained their original color very soon when placed again in the dark. The sulphur-yellow powder immediately darkened in strong light, without becoming orange, however. These color changes could be reproduced at will as often as desired. The contrast in color between exposed specimens and those protected from light was most pronounced and could be strikingly seen by disturbing the contents of a small tray of the mineral fragments. The unexposed parts thus brought to the surface contrasted strongly with those that were still undisturbed. An opposite change has been noticed in East Indian sodalite from Rajputana by T. H. Holland.[a] In this mineral the original carmine color faded out in bright light, but was restored after some weeks in the dark.

It was also noticed that the exposed crystals were not all of the same color; there were some that had not changed at all, and others that showed all gradations between almost colorless and orange, and one was seen with a dark hexagonal core and a light outer zone. Professor Sachs noticed a similar association of colors. One of the first specimens received was composed entirely of pale-yellow coherent crystal masses, held together by or holding together an earthy reddish gangue. It was suspected that with this difference in color might go a certain chemical dissimilarity, nothwithstanding absolute identity of form and qualitative behavior; therefore the lightest colored crystals and aggregates were picked out and separately analyzed. In disagreement with Professor Sachs, no certain evidence of difference in composition between the permanent and changeable crystals was shown by the analyses (p. 41). It should be said that even the lighter-colored material that was picked out from the samples of loose crystals varied in color, but in mass was very much lighter than the rest in daylight, although it is probable that light was not wholly without effect on it.

The original color of the mineral in the mine is evidently almost canary yellow for the most part, grading from this to a very pale yellow. The permanence of the color of kleinite, except as to the deepening mentioned, makes it easy to distinguish the mineral from eglestonite and terlinguaite after exposure to light, for the former of these turns brown, then black, the latter gray-green, or perhaps olive-green when earthy.

In transmitted light the crystals vary in shades of yellow corresponding to those seen by reflected light. No pleochroism was noticed. Most of the kleinite is opaque, being in a somewhat granular crystalline state, but the minute crystals that are bounded by

[a] Geol. Mag., vol. 3, 1906, p. 519.

smooth faces are fairly transparent to translucent. Some of this opacity is doubtless due to the inclusion of an opaque dust. (See "Optical properties.")

The streak is pale yellow, immediately darkening, but regaining its color in the dark.

OPTICAL PROPERTIES.

The mineral being geometrically hexagonal, a basal section should remain dark under crossed nicols. But, as described by Moses, such a section shows double refraction, and if thin enough will be seen to be composed of innumerable individuals, none of which is large enough to show interference figures. The double refraction is strong, the colors being of the third and higher orders. At about 130° the double refraction begins to decrease, as seen by the descending colors, until finally it becomes zero and the mineral remains dark under crossed nicols. The section now gives a uniaxial, positive interference figure. Upon cooling, the section remains dark, but after the lapse of many months is seen to be slowly returning to its doubly refracting condition. This phenomenon seems to show that kleinite is dimorphous and that the uniaxial optical state agreeing with its outward hexagonal form is stable only above 130° approximately, while below that temperature its stable condition is biaxial, probably triclinic. According to this the hexagonal crystals of kleinite must have been formed at a temperature not much, if any, below 130°. As is stated just below, it is at a point but a few degrees higher than this that the first permanent browning of the mineral becomes visible when it is heated, and considerable loss of water has then taken place. What connection, if any, there may be between these two phenomena is not known.

The foregoing paragraph gives the essential features of the optical phenomena, which will now be given in more detail.

Most of the sections, viewed under the microscope, showed no difference when the nicols were crossed. As much light passed through as when the nicols were not crossed, and on revolving the stage of the microscope there was not the slightest indication of any extinction. When, however, a basal section was ground down thin enough, or a natural cleavage piece of sufficient thinness was observed, it was found that parts of the section would show extinction while other parts remained uniformly light. The thinnest sections were seen to be composed of a large number of crystal units with no definite shape or orientation either to each other or to the hexagonal outline of the section. Some of these extinguished, others did not. Where there was a straight edge to one of these apparently homogeneous units, the extinction to this edge was oblique. Some of these units seemed to show indications of a biaxial brush when tested for an interference figure, but no definite result was obtained. A dia-

grammatic view of such a section is shown in figure 3, where the shaded portions represent the parts that showed extinction. The outline of these parts is usually indefinite, and there were also numerous smaller areas, often no larger than a point, that showed extinction, but which are not shown in the figure. These areas did not extinguish at the same time; in fact, no two areas were found that extinguished together. As can be seen, the light part representing the part of the section that showed no extinction whatsoever on a revolution of the stage of the microscope is by far the larger part of the section. From a study of various sections it appears probable that it is merely due to the thickness of the section that parts do not extinguish. As is well known, a section made up of superimposed biaxial plates will give a resultant grouping that will not extinguish. Such a phenomenon is common with some micas, the superimposed plates of which are often in twin position. With kleinite, however, there is probably no twinning, but simply a superimposition of plates of biaxial material, with a result that a basal section of kleinite will in general show no extinction. If a section be ground so thin that the thickness is not greater than that of any of the individual plates, then the entire section will show extinction, but not uniformly. Such sections as show extinction have a very high birefringence, since in the thinnest sections obtainable the colors are all high in the third order and above. It should be remarked, however, that the brittleness of the mineral is a serious detriment to the grinding of very thin sections, as the mineral will often crumble to pieces and the section be lost.

FIGURE 3.—Diagrammatic sketch of basal section of kleinite showing optical unhomogeneity, in polarized light, nicols crossed.

The fact that the mineral undergoes an optical change at about 130° was found by accident. A section which showed some areas that extinguished, but of which the greater part showed no extinction, was being mounted in Canada balsam in order to grind the section still thinner. When the slide had cooled, it was found that the section remained dark under crossed nicols; and the section was found on testing to give a uniaxial, positive interference figure. In other words, the section behaved as a basal section of a hexagonal mineral would.

The explanation of the phenomenon is, of course, that the optical state agreeing with the hexagonal geometrical form is not stable for the ordinary temperature, but has a range of stability from about 130° to the temperature at which the mineral is decomposed. In

other words, the mineral is dimorphous. From the fact that the extinction in such sections of the mineral as show extinction was always oblique and that apparently parts of a biaxial interference figure could sometimes be seen, the state or condition in which the mineral is stable below approximately 130° is that of either the monoclinic or the triclinic system, and probably the latter.

The particular section in which the change to the optically uniaxial condition was first noticed did not soon revert to the doubly refracting state on cooling, but now, thirty months after the section was heated, almost its entire substance is again doubly refracting, only a very few points remaining dark. Therefore the complete reversion of the entire section from the uniaxial to the biaxial condition takes place, though the change is a very slow one.

After the above facts had been ascertained, the attempt was made to find the exact temperature at which the change took place. Two natural cleavage pieces of sufficient thinness were found and these were heated as follows:

A "heating apparatus" for a goniometer (probably for a universal apparatus of Groth's type) was placed on the stage of the microscope and heated from both ends by two low flames. The thermometers were inserted between the flames and the mineral section, which rested on a glass slide. The heating apparatus was properly insulated by being covered with asbestos, and the mineral section could easily be observed by the microscope. With nicols crossed, the section was watched as the temperature rose, and reversion of the mineral to a uniaxial condition was observed as the colors decreased in the regular scale and finally became black. The following table shows the result of the heating of such basal sections, two different experiments being made. The temperatures given, T_1 and T_2, it must be understood, are those read on the two thermometers and are not necessarily the temperature of the mineral. Readings were taken every minute.

Effect of heating first basal section of kleinite.

Time (a. m.).	T_1.	T_2.	Remarks.
	°*C.*	°*C.*	
9.54	....	....	
10.11	126	127	First change noted.
10.15	138	138	Decided change in color.
10.17	142	142	Decided change.
10.19	145	146	Became dark in spots.
10.20	147	148	About one-third section dark.
10.21	149	149	About one-half section dark.
10.22	151	151	Becoming dark rapidly.
10.23	152	152	About two-thirds dark.
10.25	154	154	Almost completely dark.

Effect of heating second basal section of kleinite.

Time (p. m.).	T_1.	T_2.	Remarks.
	°C.	°C.	
12. 30	....	....	
12. 48	127	127	Color begins to change.
12. 49	....	....	Heat removed.
12. 50	130	130	Color change decided.
12. 52	128	128	Change stops.
12. 53	....	....	Heat reapplied.
1. 03	130	130	Color change again commences.
1. 07	137	137	Section becomes dark in spots.
1. 08	....	....	Heat removed.
1. 14	....	....	Heat reapplied.
1. 37	140	140	Change very rapid.
1. 40	142	142	Section almost entirely dark.
1. 42	....	....	Heat increased.
1. 45	160	160	Only a few bright spots left.
....	170	....	A few bright spots still remain.

From some preliminary observations made on sections so thick that they showed no extinction, it was found that the change would take place only in very thin sections. Some of the thicker pieces were heated to 175° without the slightest change taking place. Even the thinnest sections did not become entirely dark, for there were small areas that continued to be doubly refracting for 40° above the inversion point. These areas, however, were such as showed no extinction and did not change because of their thickness. The "molecular inertia" of kleinite would seem to be considerable.

An attempt was made to show these changes photographically. In Plate I are reproduced three photomicrographs of a basal section of kleinite: *A* shows a view of the mineral as it appeared under the microscope in polarized light, the nicols not being crossed; *B* is the same view with the nicols crossed. While most of the section is doubly refracting, it can be noticed that parts are dark. The section was so placed as to show the maximum amount of extinction. The section was then removed, heated up to about 150°, allowed to cool, and photographed under crossed nicols with the result shown in *C*. With the nicols not crossed the result was the same as in *A*, but the decided difference between *B* and *C* can be seen at a glance. During the manipulation of the section in mounting it for photographing the section became inverted, which accounts for the difference in outline of the fragment. Though heated considerably above 130°, the section still shows considerable area which has not become dark and therefore still retains its birefracting condition.

The sections do not show any pleochroism, and an approximate determination of the mean index of refraction gave a value of about 1.8. The index of refraction would then be considerably lower than that of the other mercury minerals, which fact is in accord with the less brilliant luster of kleinite.

BASAL SECTION OF KLEINITE SHOWING OPTICAL UNHOMOGENEITY.

A, Nicols not crossed; *B*, nicols crossed; *C*, nicols crossed, after the section had been heated to 150° and allowed to cool.

CHEMISTRY.

GENERAL CHARACTERISTICS.

QUALITY OF THE MATERIAL.

While many of the single crystals and crystal aggregates of kleinite were very fine and brilliant, much of the material was far too impure or altered for the chemical tests that were contemplated. It was not difficult to pick out much that was of fair quality, though none was quite faultless, and herein lay the chief obstacle to a satisfactory determination of the actual composition of the crystals themselves, for the water shown by the analysis comes without doubt in part at least from the earthy matter that it was impossible to exclude. Many of the qualitative and orienting quantitative tests were carried out on relatively impure crystals, but most of the quantitative work was done on selected crystals, though the nonvolatile residue from these several portions was in none less than 0.75 per cent, and in one was 3 per cent. Even had it been possible to select crystals absolutely free from external contamination of this kind there would still have remained the difficulty presented by the nonvolatile matter that seemed to permeate the clearest crystals, almost as if in solution, to judge from the microscopic evidence and from the fact that when heated they left a residue similar in its general character to that which was evident to the eye. The majority of the selected crystals were slightly clouded by foreign matter.

PYROGNOSTIC CHARACTERS.

When carefully heated in a closed tube, or in one through which passes a current of air, the mineral loses a little water, begins to brown at 135° to 150°, and as the temperature rises becomes still darker and yields more water, but gives no other visible sublimate under 260° even after several hours, though once or twice a gold-leaf plug at the constricted outlet of the tube showed slight amalgamation long before a sublimate appeared. Between 260° and 280° mercury and calomel sublime and condense in part together, but most of the mercury just in front of the calomel, the latter being pale yellow when hot. When most of the calomel has passed off, the residue begins to grow lighter colored, then yellowish, and finally nearly white. During the expulsion of the calomel some gas is evolved in minute amount that sets iodine free from potassium iodide solution. (See p. 30.) On increasing the heat to 400° more of this active gas is evolved, but it is soon followed or accompanied by another that destroys the color of the free iodine. Accompanying the decomposition or volatilization of the white residue at 400°–420° appears a further sublimate less volatile than the calomel. If the test is made in a small closed assay tube this last sublimate and the still unvolatilized

residue may melt to a dark reddish liquid, which, on cooling, solidifies with a yellowish and then white color. Ammonia turns both sublimates black instantaneously. In the sublimate appearing at the lower temperature can be found all the chlorine of the mineral except a small amount that seems to escape in the free state. (See p. 30.) Below about 400° nearly all the sulphur is to be found in the residue as mercuric sulphate, and after disappearance of the residue it is mostly in the less volatile sublimate as both mercuric and mercurous sulphate, the relative amounts seeming to depend on the rapidity of the heating.

Most of the nitrogen of the mineral escapes in the elemental state during the formation of the calomel, but not quite all. There is not the least evidence of the formation of ammonia. If the heating is carried out in vacuo the evolution of the active gas, already referred to as taking place during the later stage, is much more marked than at atmospheric pressure.

QUALITATIVE BEHAVIOR TOWARD REAGENTS.

The mineral is soluble in warm hydrochloric as well as nitric acid without deposition of calomel, hence the mercury is in the bivalent state. It is also soluble in sodium sulphide and in ammonium bromide. Ammonium bromide liberates as ammonia for every one part of nitrogen derived from the mineral itself three parts from the reagent. The fixed alkalies do not liberate ammonia. Hydrogen sulphide blackens it speedily, but very superficially. When the mineral is boiled with sodium sulphide for the determination of nitrogen as ammonia much of the mercury often separates in the free state.

ADDITIONAL DATA.

Numerous observations that were made during the quantitative tests will now be detailed, since they bear on the ultimate elucidation of the true nature of the mineral, though it must be confessed that the explanation of some of them is as yet obscure.

DATA RELATING CHIEFLY TO OXYGEN, NITROGEN, AND CHLORINE.

Starting with the idea that the mineral was probably an oxychloride of the same general character as eglestonite and terlinguaite, the first efforts aimed at a direct determination of the oxygen, after decomposing the mineral in a current of carbon dioxide and collecting the gas in a nitrometer over potassium hydroxide solution. The permanence of the gas when tested with alkaline pyrogallate caused the oxychloride hypothesis to be discarded and suggested the need for similar direct tests on eglestonite, terlinguaite, and montroydite, in order to have indisputable proof of the existence of oxygen in them and that the assumed oxygen was wholly such. The probable identity of the gas from kleinite was shown by the

well-known test of Lassaigne for the detection of nitrogen in organic bodies, modifying it to the extent of mixing the mineral powder with sugar before heating with sodium. Full proof was afforded by the spectroscopic test kindly made by Dr. P. G. Nutting of the Bureau of Standards. Doctor Nutting on volatilizing a few crystals in an evacuated tube observed no evidence of any of the common gases besides nitrogen and chlorine, though the absence of oxygen could not be asserted owing to the difficulty of its recognition spectroscopically. He reported, however, a faint helium line, which was observed only on the first warming of the mineral. The practically entire absence of radioactivity, as reported by Doctor Boltwood, seems to be in conflict with this observation of Doctor Nutting. The gas was examined by us during our earlier experiments at different stages of its expulsion, using a small spectroscope, and while the different spectra of nitrogen were always in evidence, according to the degree of evacuation of the tubes, no peculiarities were observed that suggested appreciable if any admixture of another gas. When the gas was exposed to phosphorus after contact with solid sodium hydroxide, on at least two occasions evidence of the presence of a little oxygen was very positive. (See next paragraph for its probable source.) Several portions of gas that had been exposed to alkali and phosphorus were combined and passed over hot magnesium, the result being almost complete disappearance of the gas; that unabsorbed was hydrogen that had apparently come from the magnesium itself.

The derivation of the oxygen just mentioned is of much importance, for it might originate from a basic mercury compound and then have to be reported as well as the oxygen of the SO_4, or it might be of secondary origin, or it might derive from both sources. It has already been said that it was found possible to separate almost quantitatively the chlorine from the sulphur by slow and careful heating of the mineral, the former volatilizing as calomel, the latter remaining as mercuric sulphate. When this separation was effective, that is, when the chlorine could be recovered almost entirely from the sublimate and no sulphur was to be found with it, then no oxygen was detected with the nitrogen, and nearly all of this latter element had passed out of the mineral. If, on the other hand, the heating was carried to the point of volatilization of the residual sulphate (about 400° to 420°) partial decomposition of this salt often resulted, but not always. (When the sulphate was quickly heated in an assay tube closed at one end a strong odor of sulphur dioxide became apparent.) This partial decomposition must have been accompanied by the liberation of oxygen. The oxygen, if of secondary origin, would result either from direct breaking up of the sulphate radicle or from interaction between the mercury sulphate and the basic constituents of the nonvolatile gangue that was always present

in varying amount. Sometimes the whole of the sulphur was recoverable from the sublimate that was produced at about 420°; at other times not, but in the former case oxygen seemed to be absent from the gas collected by the pump, and this fact is an argument against assuming a basic salt of mercury as the source of the oxygen.

An attempt to determine the actual composition of the sulphate, not volatile below 400° to 420°, was not very successful. In one experiment a ratio of near 2HgO to $3SO_3$ was obtained, indicative of an acid sulphate, but the needlessness of this assumption is evident when it is considered that the nonvolatile gangue that is always present contains basic substances that are able to bind the sulphate radicle at the temperature employed. A further reason for lack of success was the presence of a small amount of nitrogen (0.05 per cent in one case, 0.20 per cent in another), which indicated either that some of the chloriferous constituent had not been decomposed or that an analogous sulphato compound was present. The results seem to show, however, the probability that the nitrogen belongs mostly, if not entirely, with the chlorine in the mineral and to a limited extent, if at all, with the sulphur.

Another observation, which at first seemed to have important bearing on the union of the nitrogen and chlorine in the mineral, was the already mentioned appearance (p. 27) of an active gas capable of setting free iodine from potassium iodide. This reaction was much intensified by heating the mineral in vacuo, and produced serious disturbance in the first quantitative tests involving the use of a Töpler pump. No action of the active gas was apparent in the pump until in the process of transferring the nitrogen to a collecting tube the hitherto expanded gas became compressed to nearly normal density, when it instantly fouled the mercury in the long fall or outlet tube, and also that in the collecting tube. The pump was on one occasion put out of working order until taken apart and cleaned, and several times the gas above the mercury in the collecting tube had exactly the color of chlorine. Agitation of the mercury contents of the tube quickly caused the color to disappear and qualitative test of the scum on the mercury revealed the presence of much chlorine. The formation of this free chlorine could not be fully prevented in vacuo, even when the mineral was first mixed with much lime or sodium carbonate, but it became less as the pressure was increased and a vanishing quantity when the pressure was normal. On one occasion, after heating the mixture under reduced pressure in a platinum boat, the latter was found badly attacked, as after a niter fusion. The phenomenon seemed incompatible with direct union of chlorine and mercury in the molecule, until it was shown that a similar reaction takes place when a mercuric sulphate ($3HgO.SO_3$ in the test) is heated with a mercury-ammonium chloride ($NHg_2Cl.xH_2O$). The mercuric sulphate in breaking up doubtless liberates active

oxygen (or some active oxide of sulphur?) which acts on either the calomel already sublimed or on still undecomposed chloriferous mineral, setting free chlorine. The free chlorine does not begin to manifest itself till about one quarter of the nitrogen has been expelled. Interposition of a long layer of silver turnings was quite without effect in retaining the chlorine when under reduced pressure.

When decomposition of the mineral is effected by heating it in admixture with sodium carbonate to a sufficient temperature to fully break up the resulting mercuric oxide into its elements, oxygen is liberated in quantity. Theoretically the amount should be exactly equivalent to the SO_4 and Cl_2 found in the particular sample (see p. 35) if the compound is normal and not basic. As a matter of fact, it never did equal the calculated amount, which has a mean value of 2.14 per cent of the weight of the gangue-free mineral, but was rather uniformly between 1.75 and 1.85 per cent, never reaching 2 per cent. No positive explanation for this seemingly anomalous behavior has been found. Various explanations suggest themselves, as the formation of a gaseous oxide of nitrogen or of sodium nitrite or nitrate or of one of the chloroxy salts of sodium. No evidence of a volatile nitrogen compound was obtained, though there was an indication of a retention of oxygen by the flux, for when tested in sulphuric acid solution with diphenylamin a pronounced blue color appeared. From the temperature employed in the experiment of decomposing the mineral it seemed improbable that the effect could have been produced by a hypochlorite or chlorate; in fact, a test for chlorate chlorine proved negative. In another experiment 0.07 per cent of perchlorate chlorine was found after removing the chlorine of other salts, but owing to the small amount of kleinite operated on (0.3 gram) this is not to be regarded as a conclusive test.

A quantitative test for nitrite or nitrate nitrogen was made as follows: After decomposition of the mineral the aqueous solution of the sodium carbonate was acidified with sulphuric acid, chlorine was precipitated by silver sulphate (7.23 per cent Cl found), to the filtrate excess of chlorine-free sodium hydroxide was added, the solution boiled, aluminum powder then added and the boiling continued as for the Nessler test, the ammonia being collected in hydrochloric acid and determined as chlorplatinate. There was found 0.00033 gram nitrogen, or 0.10 per cent (0.35 gram kleinite used). From the acidified solution left in the flask 0.00037 gram chlorine was obtained, or 0.10 per cent, which added to that first found makes a total of 7.33 per cent (analysis 4*a*). It is uncertain how much weight should be given to these determinations, which were not duplicated, because the absolute amounts involved were so very small that no positive proof seemed realizable with the available material, but if approximately correct the values for nitrogen and chlorine are of a magnitude sufficient to account for the above calculated deficiency in oxygen set

free on heating the mineral with sodium carbonate. They probably represent maxima, since in many analyses the chlorine obtained directly from the flux equaled the sum of the two portions above found separately. Of course if such a retention of nitrogen was of constant occurrence in all analyses made with sodium carbonate the mean value for nitrogen given later is slightly low. It is assumed that any oxygenated salts of sodium and chlorine, if actually present in the flux, were formed during the experiment and did not preexist as mercury salts in the mineral.

DATA RELATING TO WATER AND HYDROGEN.

Notwithstanding the failure to find any positive evidence of the evolution of elemental hydrogen or oxygen on heating the mineral by itself, water was evolved. It is certain that this came in part from the clayey gangue and sometimes from traces of gypsum, but there was never enough of these to account for more than a small part of the whole. The presence of the gangue in varying amounts in the different samples examined has proved a serious stumbling block to the exact determination of some of the constituents of the mercury mineral, besides necessitating a far greater number of quantitative tests than would otherwise have been called for. The results for water, furthermore, vary so widely (0.49 to 1.20 per cent) in the different samples that they constitute the weakest link in the chain of quantitative data and little can legitimately be concluded as to the part the hydrogen and oxygen play in the structure of the mineral. It is conceivable that the water, or some of it, particularly of the last portions that came off, may have been derived from oxygen and hydrogen existing in the form of hydroxyl, or even not in direct mutual union in the mineral, though the latter seems a quite unwarranted supposition. None of it is hygroscopic in the common sense, about one-half comes off at a relatively low temperature (under 135°–150°, the temperature at which permanent browning of the powder begins), and the total amount found by combustion with copper oxide, preceded in the tube by lead chromate and a roll of copper, was no more than that obtained by heating alone or with dry sodium carbonate. Hence it seems probable that, if not water of crystallization, the combination is that of hydroxyl, though it may exist in a state of solution.[a] The water determinations were, furthermore, rendered difficult by the uncertainty in some cases that the increase in weight of the absorption tube represented nothing but water, for it was difficult and not always possible to be sure that small amounts of other substances were not carried out of the tube of decomposition and collected with the water.

[a] That much, and sometimes all, of the water of many hydrous minerals is in a state of solution and does not enter into the chemical molecules, either as hydroxyl or as water of crystallization, is beginning to dawn on mineralogists. Consult the important contribution to the subject by Fr. Zambonini (Mem. Accad. sci. fis. e mat. di Napoli, vol. 14, ser. 2a, No. 1, 1908).

For the purpose of throwing light on the function of the water the nearest artificial representative of the class of bodies to which kleinite apparently belongs was prepared and analyzed in the same way as kleinite itself. This is the compound having the empirical composition $NHg_2Cl.xH_2O$, and it was prepared by long boiling of "infusible white precipitate" with water. It was found not to have quite the theoretical composition, but its properties were in many respects those of kleinite and the concordant values obtained in its analysis favor the correctness of the methods employed for kleinite, in which, however, as is evident from what has gone before, the presence of sulphur and gangue introduce decided complications.

Analyses of artificial mercury-ammonium chloride.

	1.	2.	3.	Mean.	Theory ($NHg_2Cl.\frac{1}{2}H_2O$).
Hg	86.90	87.06	....	86.98	87.25
Cl	8.69	8.56	8.63	8.63	7.73
N	[a] 2.71	[b] 2.70	....	2.71	3.06
H_2O	1.60	1.61	....	1.60	1.96
	....	....	....	99.92	100.00

[a] Determined as NH_3 by decomposition with Na_2S. [b] Determined as nitrogen gas.

The water in this compound was driven out by simply heating the substance in a tube provided with gold leaf at the exit and collecting the water in one filled with calcium chloride, and it was noticed that much—in fact, about three-fourths—of the water came off before the appearance of a sublimate of calomel and mercury. No evidence of free chlorine was to be had when the compound was decomposed in vacuo.

ANALYTICAL METHODS EMPLOYED AND THE RESULTS.

Although some reference has been made in the foregoing to methods of analysis, those employed for determining the chief constituents need further notice.

NITROGEN.

Three methods were employed in determining nitrogen: (1) Expulsion as ammonia by sodium sulphide, with collection of the ammonia in hydrochloric acid and gravimetric determination as chloroplatinate; (2) expulsion as ammonia by ammonium bromide in a closed vessel, collection of the liberated ammonia in an excess of titrated oxalic acid, and determination by standard alkali of the acid left over;[a] (3) direct determination as nitrogen gas, collected by the aid of a Töpler pump and measured in a gas burette after freeing from other gases.

[a] Pesci, L., Gazz. chim. ital., vol. 19, 1889, p. 512.

These methods and the observations made in connection with them will now be considered, not only for their bearing on the particular problem, but also for the aid of future investigators in the examination of this or similar minerals.

1. Little need be said regarding the sodium-sulphide method. The mineral dissolves with ease in sodium sulphide, generally with liberation of much but no fixed amount of metallic mercury, three determinations having given from 25 to 28 per cent, another only 4.97, and a fourth none at all. It is not thought that this behavior has any bearing on the mode of combination of the mercury in the mineral; if it had, the results should have been in better agreement. The values for nitrogen reported in the table of analyses have been calculated from the weighed chloroplatinate by the factor 0.06283, which is afforded by the atomic weights 197.2 for Pt, 35.45 for Cl, 14.01 for N, and 1.008 for H.

2. The ammonium-bromide method depends on the liberation of the nitrogen united to mercury in the so-called mercury-ammonium compounds and also three times as much from the reagent, all in the form of ammonia. The powdered mineral (0.3 to 0.5 gram) was spread on a very large inverted porcelain crucible cover, which floated on a shallow layer of mercury in a pan. Astride of this cover was placed a large platinum triangle with its legs bent down so as to elevate the center, on which rested a watch glass containing titrated oxalic acid solution. Over this was inverted a crystallizing dish, the rim of which, entering the mercury in the pan, made a perfect seal. Just before putting this dish in place 10 cubic centimeters of a neutral and nearly saturated solution of ammonium bromide containing neutral litmus solution was run quickly upon the powder by means of a pipette. At the expiration of two days, generally before, the mineral had wholly disappeared, except for most of the gangue, and the liquid had become red, showing entire freedom from ammonia.

The results by this method, all of them made early in the investigation, taking one-quarter of the ammonia found as belonging to the mercury mineral, were uniformly higher than those obtained by either of the other methods (see below). Two explanations for this offer themselves and both may be correct. It was found that the gangue was rather markedly attacked by the bromide, and ammonia was doubtless liberated by its action. A similar excess of ammonia would appear if the mercury mineral were a basic salt or if it contained any basic component. Were the latter the only explanation a sufficient number of determinations to afford a good average would allow calculating the amount of basic oxygen, but this course could not be adopted because it was practically certain that the gangue itself liberated some, if not all, of the ammonia that was apparently in excess.

3. In the gas-volumetric method decomposition of the mineral was effected in a horizontal glass tube connected with a Töpler pump and containing gold leaf near the exit. In the first experiments, when direct evidence as to the presence of oxygen was sought, no retainer for the chlorine and sulphur was used. In these tests it was found absolutely necessary to confine the crystals or powdered mineral to a limited space at the extreme end of the tube by means of an asbestos plug, for unless this was done the material would dance about during the later stages of the heating in a most remarkable manner and be projected with violence toward the cooler end of the tube and back again as soon as heat was applied under it in its new position. In subsequent experiments, after sufficient testing of the evolution of free chlorine (p. 30), dry sodium carbonate was used in admixture with the mineral powder. Calcium oxide was far less serviceable. The use of a retainer allowed more accurate determinations of chlorine, sulphur, and mercury than when its use was dispensed with, for if all three were determined in the sublimate that resulted without a retainer there was sure to be some loss of chlorine, if not of sulphur, and the separation of these from the mercury was troublesome and productive of error, whereas with a retainer the separation was effected during the decomposition of the mineral, and the mercury had merely to be weighed after cutting off the part of the tube containing it. As already intimated, however, even here the gases had to be allowed to accumulate in the tube under their own pressure, and not to escape continuously into the pump, if retention of all the chlorine was to be expected.

It was assumed that the collected gas contained all the nitrogen of the mineral, though it is possible, in view of the evidence set forth on page 31, that a very little of it was retained by the sodium carbonate in the form of nitrite or nitrate. It would also hold, in those cases where no retainer was employed, any basic oxygen that might have been present in the kleinite as well as that set free by partial breaking up of the SO_4 radicle.

Where the retainer was used there should have been present, according to expectations, besides possible basic oxygen, an amount of oxygen equivalent to the total chlorine and sulphur, as indicated by the following hypothetical reactions:

$$2NHg_2Cl + Na_2CO_3 = 2NaCl + 4Hg + CO_2 + O + N_2.$$
$$(2NHg_2)_2SO_4 + Na_2CO_3 = Na_2SO_4 + 4Hg + CO_2 + O + N_2.$$

It has already been said (p. 31) that this last expectation was never realized and a possible explanation was there suggested. It has also been said that, while very small amounts of oxygen were found after at least two of the experiments without retainer, they were accompanied in the gas in one instance by an approximately equivalent amount of sulphur dioxide, this being indicative of derivation from SO_4 and not from a basic compound.

The gases having been collected, they were first exposed to solid potassium or sodium hydroxide as long as any contraction could be noticed. This was to remove a possible trace of chlorine not taken up by the mercury and of sulphur dioxide (from the splitting up of SO_4 when the mineral had been heated without retainer) and the carbon dioxide that was present when the retainer had been used. In the last case the carbon dioxide would probably have been exactly equivalent to the chlorine and sulphate radicles of the kleinite were it not for the action of the nonvolatile matter or gangue, which always set free an undeterminable amount of carbon dioxide. Hence the determination of this component of the gas mixture, which might under other conditions have served as a valuable check, was not attempted.

Any oxygen that might be present was removed by a bead of freshly melted and cooled phosphorus. This was allowed to rise in a tube filled with mercury and secured to the glass at the top by momentary application of a flame at the point where the bead showed, only long enough to melt it. The gas was then introduced from the burette. A thin white column of descending oxide instantly manifested itself if oxygen was present, but, absorption being very slow, the end was hastened usually by heating the bead till a bright flash resulted. The residual gas was shown to be nitrogen in one test by passing the combined products of two or three analyses over hot magnesium, which removed the whole of it, if, as is believed, the very slight residuum of hydrogen found came from the magnesium.

As intimated before (p. 32), if any nitrite or nitrate was retained by the sodium carbonate, the results for nitrogen by this method are all slightly low, but against their being so is their fair agreement among themselves and of their average with those obtained by the action of sodium sulphide and by direct solution in hydrochloric acid and subsequent precipitation as the platinum salt, which the following comparative table shows:

Nitrogen percentages by different methods.

Na_2S.	HCl.	Gas-volumetric.		NH_4Br.
		With Na_2CO_3.	Without Na_2CO_3.	
2.56	2.57	2.53	2.61	2.78
2.57		2.55	2.74	2.76
2.55		2.60	2.67	2.74
2.55		2.58	2.86	2.70
		2.43		
Av. 2.555		Av. 2.54		Av. 2.74

The single determination after solution in hydrochloric acid, the last one that was made, is regarded with great confidence. The same is true of those by the sodium-sulphide method. The greater variation among the results of the gas-volumetric tests is to be ascribed to the small amounts of mineral operated on (0.25 to 0.5 gram), the uncertainty in the burette readings in the upper section of the instrument, and the greater chance for loss or gain during the numerous manipulations involved in this method of testing. The high results by the ammonium-bromide method have been already explained (p. 34) as in all probability due, in part at least, to action of the nonvolatile gangue on the reagent; and the failure to find positive evidence of oxygen in the gases evolved on heating the mineral without flux may be taken to indicate that the excess of nitrogen found by the ammonium-bromide method is wholly due to the chemical action of the gangue matter on the ammonium bromide, and not even in part to a basic mercury salt.

MERCURY.

Mercury was determined in several ways, almost always in connection with one of the nitrogen determinations already described, in order to spare valuable material.

1. As mercury, by ignition with sodium carbonate or as in organic combustions. The mercury was obtained as such in the drawn-out end of the combustion or ignition tube nearest the outlet or in an attached Peligot tube, gold leaf being used to prevent loss. The end of the tube was cut off and weighed with its contents, most of the mercury was then poured out, the rest volatilized in an air current, and the tube and gold reweighed. Most of the determinations of the table were made in this way.

2. As mercury by electrolysis from sodium-sulphide solution. This method was employed but a few times for total mercury, but frequently for partial determinations that are not in the table, the temperature being about 70°, the current about 0.1 ampere, and the cathode a platinum plate of about 27.5 square centimeters total surface. The solutions obtained in the nitrogen determinations by sodium sulphide, after boiling out the ammonia, were not used for total mercury, because the frequent separation of mercury in the metallic state necessitated a double determination with accompanying greater liability to error.

3. As the sulphide. The solutions of the mineral in ammonium bromide, a method that was at first employed for obtaining the nitrogen as ammonia, were acidified by hydrochloric acid and precipitated by hydrogen sulphide, and the resulting mercuric sulphide was weighed, after washing with alcohol and extracting free sulphur by carbon disulphide in the manner recommended by Treadwell.

These results were in part higher than by any other method, possibly because of incomplete extraction of free sulphur. When checked by electrolysis, they were once or twice found to be high. Analyses by this method are shown under 9 and 10 of the table, page 41. Their average, however, is in all probability nearer the truth than those by method 1, and is in close agreement with the third result of analysis 8 (86.18), which was obtained by electrolysis and is regarded as very reliable.

A very small amount of the mercury is present, probably as calomel, in the gangue. The third test of analysis 8 showed about 0.16 per cent of mercury left as chloride on solution of the mineral in hydrochloric acid. That it is from the gangue is likely, since this was found, when tested separately, to afford a sublimate of calomel, and the earthy gangue generally blackens on exposure to vapors of hydrogen sulphide, whereas the kleinite is more resistant toward that reagent. The rest of the mercury is in the mercuric state.

CHLORINE AND SULPHUR.

The results for chlorine and sulphur that were obtained after decomposition of the mineral by heat in presence of sodium carbonate at atmospheric pressure are the most trustworthy. The methods of determination need no description.

For the deep-yellow to orange crystals the chlorine values are all close to 7.3 per cent, rather over than below, calculated to the gangue-free mineral. The few lower values belong to experiments in which there was observed loss of chlorine by volatilization.

The greater variation among the chlorine results for the light-yellow crystals and for those of the sulphate radicle throughout the series is evident, but it is not at all probable that any marked diversity of composition is thereby indicated, unless it be among the light-colored crystals themselves. The SO_4 determinations are probably simply less accurate than those for chlorine. But the determinations on light-colored material show variations that may be real, though it is to be noted (perhaps owing to the small amounts used for the tests) that a serious analytical error must have been incurred in analysis 12, for the figures given represent duplicates on the same sample.

The sublimates that were obtained on heating the mineral without retainer were several times analyzed, but more with a view to learning something about the changes then taking place under different conditions of treatment than to getting accurate figures for the total of their constituents, and the results do not find place in the table, though it is upon them that some of the statements made in foregoing pages were in part based.

GANGUE, WATER (HYDROGEN?).

The original gangue was doubtless hydrous, but that reported in the analyses represents the part that was not volatile on ignition, and therefore was anhydrous.

The water determinations, as before said, are far from being as consistent and satisfactory as it seemed they ought to be. Most of them were made by heating the mineral powder in a current of dry air with sodium carbonate, taking the precaution not to heat rapidly and to use a plug of gold leaf before the absorption tube. Other experiments were made in a similar way, but without sodium carbonate and with the expenditure of much more time, for with even moderately rapid heating it was found impossible to prevent some slight mechanical carrying over of mercury compounds, and there was danger of a little SO_2 counting as water. The length of time consumed in these last tests militated against their accuracy, but the gains of the absorption tube were sometimes checked against the losses of the ignition tube. At temperatures below that at which the first trace of sublimate other than water was wont to appear the losses and gains were, as a rule, almost identical. When the brown color of the powder had changed to nearly white, the losses equalled the gains of the absorption tube, plus the nitrogen, and when phosphorus pentoxide was placed in the tube the loss was practically equivalent to the nitrogen content only.

But it was also observed that when the loss was ascertained by heating in an open porcelain crucible, at a temperature below that at which any indication of sublimate should appear, the weight of the crucible after cooling in a desiccator indicated far less than had been shown by the gain of the absorption tube in the other experiments. In fact, after some hours in the desiccator the original weight of the sample might be regained. Additional water would then be visibly given off on heating this powder in a small tube. The partially dehydrated mineral seems then to possess an extraordinary attractive power for water, like that of some zeolites and other minerals, but the original color is not restored as the result of this reabsorption.

The expulsion of the water does not seem to take place at a fixed temperature, but to persist in decreasing amount so long as any chloro-nitrogen compound remains; yet it has not been proved that any such relation exists as might be gathered from the last statement. About half the water, roughly, comes off below 100° when the mineral is heated by itself.

As already said, the water comes, no doubt, in part from the gangue. To test this point, the gangue left undissolved by ammonium bromide was washed with water, alcohol, and ether, dried at room temperature, then over sulphuric acid, and finally ignited. On 0.0135 gram of the

unignited product, representing 2.7 per cent of the kleinite, there was produced an ignition loss of 0.002 gram, or 0.4 per cent of the mineral. Some of this, but not all, may have resulted from hydration effected by the action of the ammonium bromide. But that there is no general relation between the water and the gangue is indicated by the table of analyses if the water values are nearly correct, since some of those with least gangue show most water. It is practically certain that the greater part of the water was derived from the mercury mineral itself. This is the more credible, since an artificial hydrous compound, $NHg_2Cl.xH_2O$, is known, extremely similar in its behavior to kleinite at and below 100°. In it the water is said to vary between one-half and one molecule. The artificial preparation mentioned on page 33 afforded 1.6 per cent water, or a little less than one-half molecule, when tested in the same manner as the kleinite.

In order to learn if there might be hydrogen in the mineral in addition to that given off as water on direct ignition, two combustions were made with copper oxide, preceded in the tube by lead chromate and a roll of copper. The result (analysis 5) was no increase of water above that obtained with sodium carbonate. Furthermore, no trace of ammonia was afforded by decomposition of the mineral with sodium carbonate or lime. These two facts seem to show that the mineral contains no hydrogen other than as water or as hydroxyl. The results for water by different methods, the last three only fractional, are tabulated below, figured on gangue-free material. They need to be checked on larger amounts of pure mineral:

Percentage of water in kleinite as determined in different ways.

Analysis No.	By Na_2CO_3.	Analysis No.	By combustion.	Analysis No.	By heat only.
2	0.49	5a	1.14	7	1.20 in CO_2.
3	0.76	5b	1.13	5b	0.88 at 260° (air).
3a	1.06			6	0.91 at 160° (air).
8b	1.19			6	1.03 at 175°–205°.
11	1.29				

The evidence of all the tests except 2 and 3 is that those two must be low and that the general average for water might properly be raised a little by omitting them. This is the more likely from the fact that 3 and 3a represent the same sample. Accurate water determinations under the given conditions are most difficult to secure.

ANALYSES.

The various quantitative data obtained for kleinite are shown in the following table:

Analyses of kleinite.

	Deep yellow to orange crystals.																		Light and yellow crystals.					
	Miscellaneous methods.														Ammonium-bromide method.									
	1a.	1b.	2.	3a.	3b.	4a.	4b.	5a.	5b.	6.	7.	8a.	8b.	8c.	9a.	9b.	10a.	10b.	11.	12a.	12b.	13.	14.	15.
Hg	84.55		84.40	84.77	84.46	82.69	83.55	83.19	83.13			84.77	84.90	85.13	85.77	85.19	85.08	85.50	83.61	85.20		86.45	84.43	85.21
Cl	7.25		7.21	7.23	7.22	7.05	7.00	7.05		[a]7.06	[a]7.04	7.22	7.19						7.12	6.85	7.07	[b]7.18	7.36	7.19
SO_4	3.05		2.92	2.98	3.07		3.19	3.07				3.09	3.05	3.07					3.04	3.85	3.35	[c]3.41	3.04	3.31
N	2.54	2.55	2.50	2.52		2.49				2.532	2.65	2.575		2.55	2.75	2.72	2.70	2.67		2.51		2.58	2.43	
H_2O			.48	.75	1.05			1.10	1.09		1.19		1.18						1.26					
Nonvolatile	1.09		1.75	1.07		2.47		2.86		.87	.99	1.04			1.09		1.07		2.80	.60			.95	
CO_2								.46																
Specific gravity				7.967	7.99										7.96	7.98				7.944				

SAME CALCULATED TO SUBSTANCE FREE FROM GANGUE.

	1a.	1b.	2.	3a.	3b.	4a.	4b.	5a.	5b.	6.	7.	8a.	8b.	8c.	9a.	9b.	10a.	10b.	11.	12a.	12b.	13.	14.	15.
Hg	85.48		85.90	85.69	85.37	84.78	85.67	86.05	85.99			85.66	85.79	86.18	86.72	86.13	86.00	86.42	86.02	85.71			85.24	
Cl	7.33		7.34	7.31	7.30	7.23	7.18	7.29		7.12	7.13	7.28	7.25						7.33	6.89	7.11		7.43	
SO_4	3.08		2.97	3.01	3.10		3.27	3.17				3.12	3.08	3.10					3.13	3.87	3.37		3.07	
N	2.56	2.57	2.545	2.55		2.55				2.55	2.67	2.60		2.57	2.78	2.76	2.74	2.70		2.53			2.45	
H_2O			.49	.76	1.06			1.14	1.13		1.20		1.19						1.29					

[a] From sublimate of HgCl, etc. Low. [b] Low. [c] High.

DISCUSSION OF ANALYSES.

The average composition of the gangue-free kleinite, as represented by the analyses of the deeper-colored crystals, is given below, together with the atomic ratio.

Average composition and atomic ratio for deeper-colored kleinite.

Hg	[a] 85.86 ÷ 200	= 0.4293	= 2.34	
Cl	[b] 7.30 ÷ 35.45	= 0.2059	} = 1.42	
SO_4	3.10 ÷ ½(96.06)	= 0.0646		
N	2.57 ÷ 14.01	= 0.1834	= 1	
H_2O	1.03 ÷ 18.02	= 0.0571	= 0.311	
	99.86			

The general average for mercury is certainly low, for reasons already set forth. The true value is at least 86, but the difference thereby introduced in the ratio is insignificant and may be neglected. To include the values for the light-yellow crystals would affect the ratio but little, and as those values in themselves are perhaps less trustworthy than those for the deeper-colored crystals they are omitted. The molecular value for water is of little probable worth.

The ratio shows at once that there is far too little nitrogen for a general formula of the type NHg_2X, in which X represents Cl and SO_4. It is even insufficient for the chlorine alone in such a formula. The trace of calomel present and derived from the gangue (p. 38) is not enough to affect the above ratio materially. A chloro-sulphate is not known among the artificial mercury-ammonium compounds, and it seems not improbable that the mineral may be a mixture of the chlorine compound, NHg_2Cl, with one or more other salts of mercury. The simplest assumption is that one of these is mercuric chloride. If so, the residual ratio leads to a basic sulphate of mercury for the other, as shown by the following calculation, in which the SO_4 is given its proper value as a bivalent radicle:

Hg	4,293 − 2×1,834 = 625	− ½×225 = 513	= 1.59	
Cl	2,059 − 1,834 = 225	− 225 =	0	
SO_4	323			= 1
N	1,834 − 1,834 = 0			

An important objection to the assumption of admixed mercuric chloride is the solubility of this salt in water, though it is conceivable that it might be held in a condition of solid solution. To the assumption of a basic salt in addition there is the objection that no oxygen was found in the gaseous product of decomposition when the mineral was heated by itself so slowly as to prevent breaking up of the SO_4 group. It must be admitted, though, that the tests on this latter point were not so decisive as could be wished; a little oxygen given

[a] Excluding the four results by the ammonium bromide method.

[b] Excluding 4a, 4b, 6, and 7, known to be low.

off from such a combination might conceivably act on some of the already sublimed mercury or calomel, especially if in an active state, and thus escape collection in the pump, but no evidence of any such action on the sublimate was seen. The reaction with ammonium bromide would probably afford a positive indication of the presence of a basic salt if enough of the mineral absolutely free from gangue matter could be secured to afford a series of quantitative tests on this point.

If the mineral is a mixture of the bodies suggested, or of others, it would perhaps be necessary to assume a case of solid solution that would be remarkable in view of the very considerable combined percentage of the bodies that would have to be regarded as the solutes. The absence of a uniformly extinguishing field under the polarizing microscope when sections are examined at ordinary temperatures, and the uniformity of the same field above 130°, is indicative that the temperature of formation of the mineral was a relatively high one, and that it is crystallographically at least unstable below a certain point.

It is regrettable that the long labor has resulted in nothing more definite than the fixing of the mineral as the first naturally occurring member of the so-called mercury-ammonium compounds, and the refutation of the views of Professor Sachs that have already been referred to. The question as to the structure of these mercury-ammonium bodies, whether they belong to one or other of the several types that have been suggested for them, is outside the scope of this investigation.

CRYSTALLOGRAPHY.

The crystallography of kleinite has been fully described by Sachs.[a] The crystals are hexagonal and show essentially only the simple forms. The suggestion of Moses, induced by the measurements of some very poor crystals, that the crystals might have a lower symmetry, has not been substantiated. The following description applies to the crystals measured by the writer and is in entire accord with the earlier description by Sachs.

FORMS AND VALUE OF *c* AXIS.

The crystals of kleinite are very simple in their combinations, consisting of the base, pyramid, and the two prisms, *a* and *m*. On only one crystal were any additional faces noted, namely two faces of a second pyramid. The forms present are: $c\,\{0001\}$, $m\,\{10\bar{1}0\}$, $a\,\{11\bar{2}0\}$, $p\,\{10\bar{1}1\}$, and $x\,\{10\bar{1}2\}$.

The base is invariably dull and generally gives no reflection. On some natural faces there may be seen concentric markings. Cleavage

[a] Sitzungsber. K. preuss. Akad. Wiss. zu Berlin, 1905, p. 1091.

faces are fairly bright, but are all uneven and give a multitude of signals extending through a number of degrees.

The prism $m\{10\bar{1}0\}$ is large and bright, but rarely plane, many faces being uneven and especially rounded into oscillatory combination with the unit pyramid. This is especially true of the short crystals. The prism faces are striated horizontally. On crystal No. 1, $m \wedge m$ was measured as 61° 11′–61° 25′; on crystal No. 2, as 58° 50′–60° 41′; on crystal No. 3, as 59° 48′–60° 26′.

The prism $a\{11\bar{2}0\}$ is invariably a very narrow face, often so narrow as to be hardly discernible. It is probably present on all the crystals, but on account of its minuteness is not shown in most of the accompanying figures. Crystal No. 1 gave $a \wedge m$, 29° 10′–29° 56′; crystal No. 2, 28° 54′–30° 58′; crystal No. 3, 29° 30′–30° 39′.

The pyramid $p\{10\bar{1}1\}$, while present on all the crystals, varies considerably in size, even on the same crystal. The faces were mostly bright, but rounded, and some were horizontally striated. For the measurements see below.

The pyramid $x\{10\bar{1}2\}$ was noted on only one crystal, on which two adjacent faces occur, narrow but broader than line faces. They were smaller than the faces of $\{10\bar{1}1\}$ and gave poor reflections.

$$\left.\begin{array}{l}\text{Meas. } 10\bar{1}0 \wedge 10\bar{1}2 = 46° \ 11' \\ \text{Meas. } 01\bar{1}0 \wedge 01\bar{1}2 = 45° \ 43'\end{array}\right\} \text{Calc.} = 46° \ 09'.$$

The following table gives the values of ρ observed for $p\{10\bar{1}1\}$:

Values of ρ for p {1011}.

Cryst. 1.	Cryst. 2.	Cryst. 3.	Cryst. 7.	Cryst. 8.	Cryst. 10.	Cryst. 12.
° ′	° ′	° ′	° ′	° ′	° ′	° ′
61 45	62 03	62 50	61 37	61 34	63 20	62 47
63 45	62 30	62 39	62 02	61 45	62 46	62 41
64 15	62 30	62 34	62 23	61 38	62 43	62 46
		62 29	63 20	62 59	62 42	
		62 40		61 59	61 56	
				62 09		
[a] 63 15	[a] 62 21	[a] 62 38	[a] 62 21	[a] 62 01	[a] 62 41	[a] 62 45

[a] Average.

Bringing these values together we have, as the average of 29 measurements, 62° 31′.

The general average differs only 1′ from the value obtained by Sachs, namely, 62° 30′. We may therefore take 62° 30½′ as the correct value, which gives $c' = 1.6642$. A single minute makes a variation in this value of 0.0012.

Table of forms and coordinate angles for kleinite.

[Hexagonal; c=1.6642; p_0=1.9217.]

No.	Letter.	Symbol.		ϕ	ρ
		Bravais.	Gdt.		
				° ′	° ′
1	*c*	0001	0		0 00
2	*m*	$10\bar{1}0$	∞0	0 00	90 00
3	*a*	$11\bar{2}0$	∞	30 00	90 00
4	*x*	$10\bar{1}2$	½0	0 00	43 51
5	*p*	$10\bar{1}1$	10	0 00	62 31

HABIT.

The crystals are usually short prismatic, from two to three times as long as thick. On these prismatic crystals the pyramid faces are either small or relatively large, while on many the six faces of the pyramid are very unequally developed. Figures 4, 5, and 6 show the variations in the habit caused by the pyramid faces. In figure 4 the pyramids are very narrow and, as shown in the drawing, generally fairly uniform in size. In figure 5 the pyramids are of large size and here many of the *a* faces are about as broad as shown,

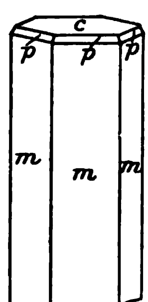


FIGURE 4.—Kleinite, short prismatic habit, with uniform development of the very narrow pyramids: $c\{0001\}$, $m\{10\bar{1}0\}$, $p\{10\bar{1}1\}$.

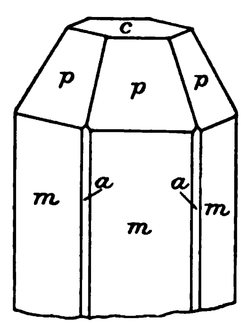


FIGURE 5.—Kleinite, short prismatic habit, with large development of the pyramid faces: $c\{0001\}$, $m\{10\bar{1}0\}$, $a\{11\bar{2}0\}$, $p\{10\bar{1}1\}$.

though elsewhere they are the merest line faces. Figure 6 shows a crystal on which the pyramid faces are very unequally developed. The line faces of *a* are not shown in figures 4 and 6, though they are probably present on every crystal.

A second habit shows crystals of approximately equal diameter in all directions. The prism faces are much shorter and the general shape of such crystals is seen in figure 7. The prism faces are more rounded than on crystals of the first habit and no accurate measurements could be made.

SUMMARY.

Kleinite is hexagonal, $c = 1.6642$, with five forms. Cleavage, good parallel to {0001} and imperfect parallel to {10$\bar{1}$0}. Brittle. Occurs as single crystals, rarely over 1 millimeter in length, and as aggregates. Luster, adamantine to greasy on bright surfaces. Original color probably bright yellow for the most part, but grading to nearly colorless exceptionally. The bright-yellow crystals are peculiarly prone to darken almost to orange in daylight, but regain their original color very soon in the dark. Color of powder, sulphur yellow. Density as determined, about 7.98, but probably over 8 for absolutely pure material. Hardness, apparently slightly over 3.5. Not radioactive. Optically a basal section shows double refraction, but on heating to about 130° becomes singly refracting, being uniaxial, positive. On cooling, the section reverts very slowly, several years being necessary for the change. This indicates dimorphism and a temperature of formation of above 130°.

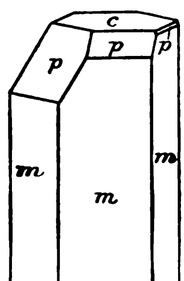


FIGURE 6.—Kleinite, short prismatic habit, with unequal development of the pyramid faces: c{0001}, m{10$\bar{1}$0}, p{10$\bar{1}$1}.

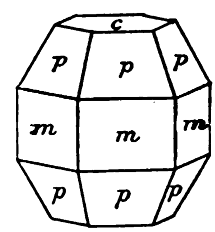


FIGURE 7.—Kleinite, equidimensional habit: c{0001}, m{10$\bar{1}$0}, p{10$\bar{1}$1}.

In the closed tube water first appears, the mineral darkens, then mercury and calomel sublimates form, followed at a much higher temperature by a sublimate of mercury sulphates. Most of the nitrogen escapes during the formation of the calomel. No ammonia is formed. A trace of free chlorine is given off at the higher temperature (much in vacuo). This seems to be due to secondary reactions. Sometimes a little sulphur dioxide is noticeable. Soluble in warm hydrochloric and nitric acids without separation of calomel; in sodium sulphide and ammonium bromide with liberation of ammonia. Fixed alkalies do not liberate ammonia, even at boiling heat. Hydrogen sulphide blackens, ammonia does not. No positive evidence could be gained as to the presence of more hydrogen than that afforded as water or of more oxygen than that in the water and SO_4 radicle, but there is some doubtful evidence in favor of a little basic oxygen. The analytical methods are discussed and the results for nitrogen by several methods (including direct gas-volumetric)

are tabulated. No certain difference could be detected in the composition of the orange and the light-yellow crystals. No positive conclusion is reached as to the molecular constitution of the mineral, which may possibly be a mixture of mercury-ammonium chloride, NHg_2Cl, in great preponderance, with an oxychloride and a sulphate or oxysulphate of mercury.

MONTROYDITE.

FORMS.

Montroydite may be said to occur under two broad aspects: (1) As distinct individual crystals of macroscopic size, usually found separate, and (2) as aggregates of minute crystals or crystalline masses. Each of these divisions is again subdivided into several groups, as follows:

1*a*. As long red prismatic crystals, commonly between 1 and 2 centimeters long and usually less than 1 millimeter thick.

1*b*. As equidimensional crystals a few millimeters thick.

1*c*. As flattened and striated distorted crystals several millimeters across.

2*a*. As brown to orange worm-like masses consisting of minute prismatic crystals.

2*b*. As aggregations of small spheres, usually 1 millimeter in diameter, but becoming cylindrical in shape and grading into 2*a* and 2*d*.

2*c*. As hollow pipe stems and also irregularly shaped masses consisting usually of minute prismatic crystals.

2*d*. As hollow, irregular, spherical masses, resembling bubbles and made up of crystalline montroydite, usually of a dark-brown color. In these hollows or geodes are found large red prismatic crystals (1*a*) and also drusy coatings of dark-colored minute prismatic crystals.

2*e*. As irregular dark-red masses showing on the surface large areas belonging to one crystal face, but no distinct crystals.

2*f*. As a nearly parallel stratified layer of dark-colored crystalline material often mixed with some of the other phases.

2*g*. As a powdery material of a brilliant light-orange color, and consisting of minute crystals.

Even though ten divisions are indicated above, it is not always easy to refer a given specimen to one of them, for many of the different phases are intimately mixed and also show varying gradations. The colors are also not characteristic, since they largely depend on the size of the outside layer of montroydite crystals. In the large crystals it is a deep red, but as they decrease in size the color becomes orange and brown, and often has a decided yellowish tint, especially in crystals that are so minute that one receives the effect of transmitted as well as reflected light. In very thin crystals the transmitted light is pale yellow, while in the larger ones it is of deep orange

shades. The more massive phases of montroydite often have a dark color, and the presence of greenish terlinguaite intimately mixed with some of the montroydite further affects the resultant color. It is believed, however, that the foregoing subdivisions cover all the essential forms, and that a description of any particular specimen of montroydite may be referred to one or more of them.

Each of the ten divisions will now be taken up and described in some detail.

1*a*. The long, red, prismatic crystals reach a maximum length of about 2½ centimeters, such long ones, however, being rare. Many reach a length of 2 centimeters, while 1½ centimeters is common. They are rarely over 1 millimeter thick, and usually a little less. The crystals are not all uniform in their thickness, many bulging out, and a little farther along resuming their ordinary thickness. These bulgings, usually only a few millimeters long, are often terminated by steep forms. Most of the crystals are found singly, though occasionally more or less parallel groups are seen. The crystals are usually terminated only at one end, the other extremity tapering down to a point, and it is usually the terminated end by which they are attached, the tapering end projecting freely into space. They are not, however, uniformly attached to the matrix by one end, many being attached by the side or by another montroydite crystal, which in turn is also attached by the side. There they are more apt to be doubly terminated than where the crystal is attached by one extremity. Though some of them are united directly to the calcite crystals, most of the long needles spring from a layer of crystalline montroydite, which rests on the calcite. Some of the crystals are accurately in parallel position, either joined symmetrically so that the resulting group is no longer than the crystals themselves or else so joined that the resulting group is several times as long as a crystal. No case was observed, however, in which two or more of these long crystals were so placed that their *c* axes actually coincided; they were always joined by a face in the prism zone. In color they are red, often a dark red with some orange, and sometimes showing a bluish iridescence, which may, however, be due to the effect of laboratory gases and not an inherent property of the mineral. Many of the crystals are covered with a greenish coating of what appears to be some mercury mineral; a satisfactory determination of it could not be made, though it seems to be largely terlinguaite. It seems remarkable that this coating is invariably nearer the end, tapering to a point; in fact, in many crystals it covers the entire point, and from there reaches to within a few millimeters of the other broader and often terminated end.

But the most curious and interesting feature of these large crystals is their flexibility. Many are found bent and torsioned, and straight crystals can be artificially distorted at will. They are apparently

MONTROYDITE SPECIMEN.

very inelastic, for after being bent no tendency to resume their original shape could be detected. Their flexibility is so great that most of the long crystals were bent and twisted when they reached us. The mineral has a perfect cleavage parallel to the brachypinacoid, *b* {010}, and when a crystal is crushed it breaks into numerous platy cleavage pieces. Many of these have a corrugated appearance on the cleavage surface similar to that which may be produced on stibnite. Some of the naturally bent crystals have developed this cleavage, and in consequence part of the crystal is frayed out into a number of plates all joined at one end, while others which are bent and torsioned show no sign of cleavage. The same effect can be produced artificially; either the crystals can be bent without showing any sign of fraying or cleaving, or the one crystal may be separated into numerous thin plates. (See further under "Physical properties," p. 52.) Crystals of this phase are shown in Plate III, and in the figures in the part of this paper devoted to the crystallography of the mineral (pp. 74 to 82).

1*b*. The equidimensional crystals are abundant, being found with the long crystals of 1*a* and also as groups by themselves. Though mostly single, they are in some specimens grouped irregularly together, or a number are in parallel position, either attached by various points of the crystals or else, though rarely, so placed in parallel position that their *c* axes coincide. Scepter crystals, in which one of the equidimensional crystals is attached to the top of a long prismatic one in parallel position, are also found. (See fig. 21, p. 82, illustrating such a crystal.) While these short crystals are found on the mass of crystalline montroydite from which the long prismatic crystals project, many of them also are directly attached to the large scalenohedral calcite crystals. These can be very well seen on part of the large specimen illustrated in Plate II, which also shows the long prismatic crystals (1*a*) as well as some of the other phases which will be referred to later.

Between these two extremes in habit, all gradations in size may be observed, the crystals becoming longer and thinner. Such a series is shown in row *a* of Plate III, where those at the left show the equidimensional crystals up to a few millimeters thick while the long prismatic ones are shown on the right. In these latter, the tapering end is pointing upward while the broader and terminated end is at the bottom. The second figure (on the left) in row *b* shows a scepter crystal which is illustrated in clinographic projection in figure 21. The remaining crystals (except the first one—see below) show some of the naturally bent prisms, which are also further illustrated under *f*.

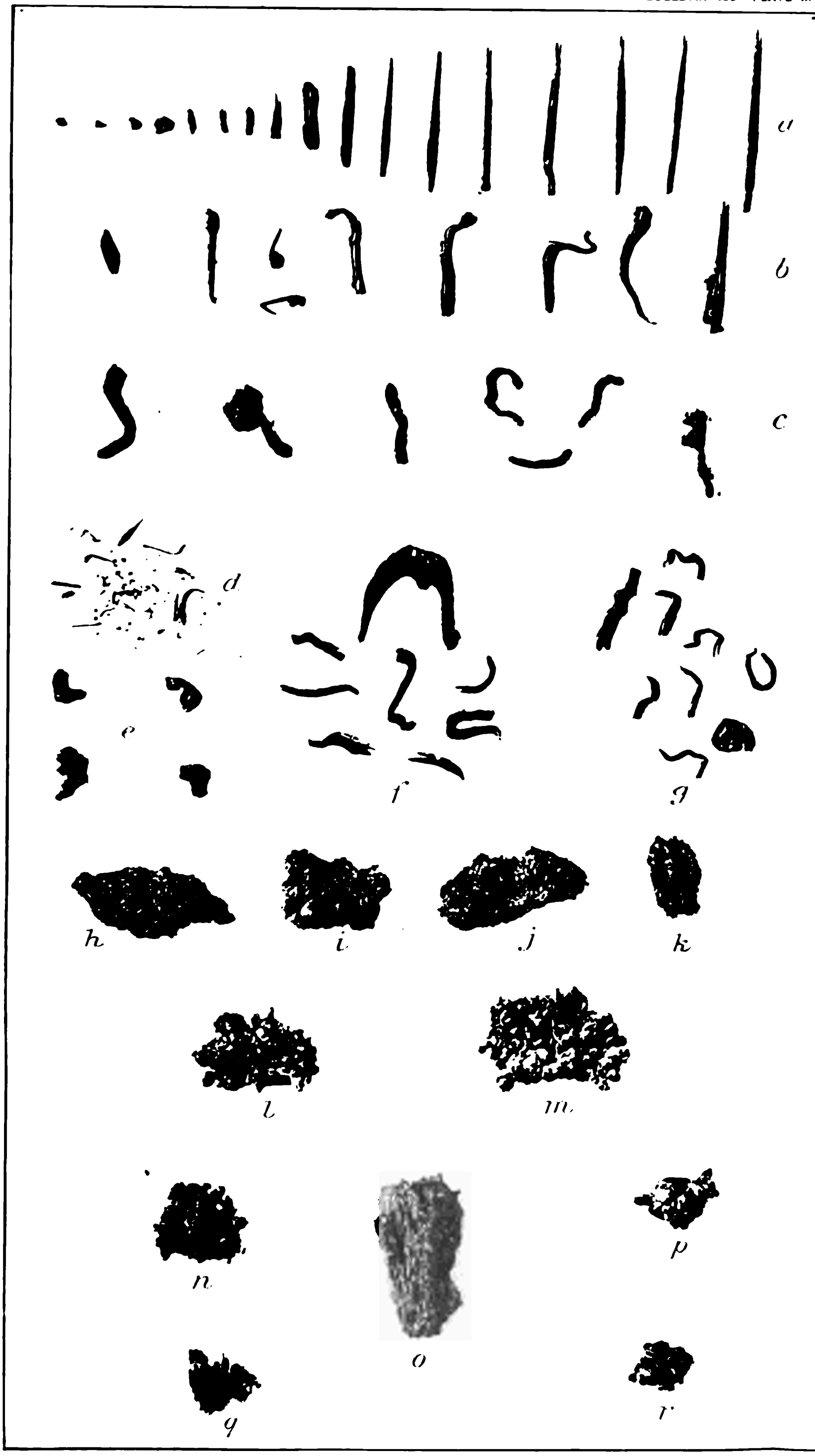
1*c*. The curious flat distorted crystals are rather rare and always imperfect, all that were seen being terminated on both sides by

cleavage faces of {010}. They are very striated and uneven and difficult to orient correctly, but it is believed that the one described and illustrated on page 82 (fig. 22) is correctly shown. Such a crystal is shown in the first figure on the left in row *b*, Plate III. Some of them are several millimeters across but few as much as a millimeter thick.

2*a*. The brown to orange wormlike masses are rather common and many are over a centimeter in length, with a thickness of about a millimeter. In color they vary from a rather dark brownish red to a light brown, many being nearly brownish yellow, depending on the fineness of texture of the outside crystal layer. A few are covered with a dark grayish mineral, apparently the same as that on the long prismatic crystals (1*a*). If one of these wormlike masses is complete, both ends are closed with the same material that forms the outside layer on the sides. When these masses are broken it is usually seen that they are cylinders partly filled with porous dark brown to red crystalline montroydite, many with a minute hollow canal in the center, but some completely filled. Rarely they are hollow, the diameter of the hollow canal being at least half the diameter of the entire mass. In those mostly filled with the porous crystalline montroydite, three concentric colors are to be seen. The innermost mass is red, that surrounding it is a dark brown or dark red, sometimes appearing nearly black, while the outside rim has the light yellow-brown color of the entire mass. Sometimes distinct small crystals can be seen in the interior porous mass, but most of it is a crystalline aggregate. The outside coating, generally very thin, of a light yellow-brown, is composed of a feltlike mass of minute prismatic crystals, so fine as to rub off like flour on the fingers. A series of illustrations of these wormlike masses can be seen in row *c*, Plate III, while *h*, same plate, shows one of these attached to a mass of crystalline montroydite.

2*b*. The small spheres are similar to the above-described wormlike masses in every way except in shape. There are so many of these spherical masses that show no tendency to form elongated groups and thus pass into 2*a* that one seems justified in classing them separately. When such spherical groups become elongated in some directions they generally grade into the forms of 2*c* rather than 2*a*.

It is a great rarity to see these spheres directly associated with the wormlike masses, though they are commonly found with the other forms, such as 2*c*, 2*d*, 2*e*, and 2*f*. When one is broken, the interior is seen to be composed of a dark-colored crystalline mass of montroydite, from which the outer shell of light-colored prismatic crystals radiates, forming a bristling sphere. Some of these prismatic crystals are extremely thin compared with their length, which probably never exceeds 0.5 millimeter, being almost hairlike, and the ratio of their



MONTROYDITE FORMS.

length to thickness is doubtless very much greater than that of the longest of the large red prismatic crystals of *1a*. Spheres in which the bristling crystals are so very thin as described are almost light-yellow in color, and are shown in *i*, *j*, *n*, *q*, *r*, Plate III.

2c. The hollow pipe-stem structure is rare on the specimens at hand, many of the groupings of minute light-colored crystals being very irregular and undefinable as to their shape. Some are partly hollow, and others are filled with crystalline material. While many such groupings are light-brown, some are rather dark, lacking the outer envelope of the velvety minute crystals. Some specimens referred to this type consist of hollow cylindrical masses, from both the outside and inside of which radiate a large number of the small minute prismatic crystals. Forms described by Moses, in which the supporting column is mercury and has the "velvety incrustation of orange-red needles" projecting from it, were not found by us. Some illustrations of specimens referred to here are shown in *l*, *m*, *n*, *p*, *q*, *r*, Plate III.

2d. The large bubble-like masses are rather common and are found implanted on the crystalline masses of montroydite, especially the form *2f*, and also between the large scalenohedral calcites, where these bubbles attain a large size. A smaller bubble on *2f*, broken open to show the hollow interior, is shown in *i*, Plate III, while several others appear in Plate II, one over a centimeter across being well shown in the central upper part. In color they are very dark, appearing almost black, and are smooth with a dull luster. While the smaller ones are nearly spherical the larger ones tend to be more irregular in shape and many appear as if made of several fused together. On breaking a number of these open it was found that they were all hollow; they thus differ markedly from the forms already described, in which the center is filled with crystalline montroydite. The inside walls of these bubbles are covered with a drusy coating of the minute dark-red colored crystals, *1b*, and rarely with the light-colored prismatic crystals which in the other forms are on the outside. The appearance of these bubbles very much resembles that of geodes. A number of them have in addition numerous large, red, prismatic crystals, *1a*, running through the interior space and of a length nearly equal to the diameter of the bubble. A number of these bubbles have considerable terlinguaite inside, this mineral, generally mixed with the montroydite, forming an aggregate of crystallized material in which the individual crystals are usually not very distinct.

2e. The irregular masses which show large crystal faces, but no distinct crystals, are rather abundant. They have a dark-red color and often a resinous appearance, reminding one very much of dark-red sphalerite. The crystal faces, some of them several millimeters

across, though generally much smaller, are always striated and uneven. Some of these masses are hollow, others more or less filled with dark-red crystalline matter. Group *e*, Plate III, shows four of these forms, though the photograph does not bring out the structure well.

2*f*. The stratified form is present in the largest quantity and contains mixed with it examples of nearly all the other forms. The large mass on the large specimen, a part of which is shown in Plate II, is slightly over 2 centimeters thick and more than a decimeter across. Its structure is not well shown in this plate, as this shows a top view looking down on the mass, but *k* and *o*, Plate III, show the stratified appearance. The layers are generally very thin and are separated from each other by spaces much higher than the thickness of each individual layer. While in general fairly parallel, in detail they are not so, at one place the layers running down to meet each other, and elsewhere two parallel ones being joined by a third slanting between them. No individual layers can be traced for any distance, since they become broken up and very irregular in shape. They are of a dark reddish-brown color and are composed of crystalline montroydite in which are embedded distinct crystals, either long or short, and usually dark-red, and also variously shaped masses of the light-brown, minute prismatic crystals. Considerable terlinguaite is mixed with this montroydite, so much at times as to give the whole mass a greenish color. Short, minute, dark-red crystals (1*b*) are rather abundant here. So far we have not found any metallic mercury mixed with this stratified material.

2*g*. The powdery material is placed in a separate class, as it was particularly noticed on a specimen where prismatic red crystals constituted the only other form of montroydite. It is the specimen on which montroydite (with terlinguaite) is found associated with calomel, the matrix being the pink earthy mass, which is here highly impregnated with calomel. The specimen when received was of an exceedingly brilliant light-orange color, the unusual lightness being due probably to the associated powdery yellowish terlinguaite, as well as to the minuteness of the montroydite crystals. After the terlinguaite had changed its yellow color to a dark greenish gray, the brilliant color of the specimen entirely disappeared.

PHYSICAL PROPERTIES.

COHESION, ETC.

The cleavage is perfect parallel to the brachypinacoid $b\{010\}$, and is obtained with the greatest ease. Sometimes when a crystal is being bent it will give at a certain point and form a sharply angular V-shaped mass, when the cleavage will cause the crystal to

separate into numerous plates parallel to the brachypinacoid. Numerous parallel straight lines on the brachypinacoid {010}, normal to the prism edges, are caused by a steplike structure on the cleavage piece. The presence of these numerous parallel lines seems to indicate that the basal pinacoid {001} is a gliding plane. But its development is very slight, as we were not able to produce artificially a plane surface parallel to {001}; neither could any such surface be detected on any of the crystals. It may be mentioned here that the base {001} has not been observed as a form for montroydite. Indications of a cleavage oblique to the length, as mentioned by Moses, were not seen on any of the crystals.

FLEXIBILITY.

The crystals are somewhat brittle, in that they may be broken into masses of irregular shape, but it is very difficult to do so on account of the excellent cleavage. Attempts to crush the mineral almost always result in forming numerous cleavage plates. The mineral is sectile, since a thin piece may be cut off with a knife, the separated piece curling as is usual with a sectile substance.

As far as qualitative tests show, the mineral is not elastic, but is flexible. In fact, as already shown, its flexibility is developed to a wonderful extent. It is possible to bend a crystal into a circle without its showing the least sign of breaking or cleaving. There does not seem to be any tendency on the part of the mineral to resume its original position, though no accurate experiments were made to prove this. The bending force must be applied normal to the cleavage face, that is, parallel to the *b* axis, when the crystal will bend in the zone (010) : (001). If the force be applied in some other direction the crystals will usually break, though not always. Moreover, measurements of some of the crystals naturally bent have shown that not only have they been bent in the zone (010) : (001), that is, in one direction, but they have also been twisted, so that they were flexible in at least two directions. One crystal that was naturally twisted as well as bent, without showing under the microscope any indication of breakage or cleavage, was measured and shown to have been bent and twisted by at least two forces. Attempts to twist a crystal artificially were not very successful, as the mineral usually cleaved into numerous plates.

Plate III shows some crystals (*g*) of montroydite that were originally straight, but have been bent into various shapes to illustrate the flexibility of the mineral, as well as some others (*f*) that were bent when received by us.

In directions other than that normal to the cleavage the crystals are fairly rigid, and, if not allowed to turn so that the stress may be applied in a direction normal to the cleavage, will either break

irregularly or cleave into numerous plates when a sufficient force is applied. Plate III, *d*, shows the result of applying to a crystal a sufficient force in a direction not normal to the cleavage. In breaking there formed numerous small pieces (result of brittleness) and also numerous platy masses (result of cleavage). These last as a secondary effect are often bent, as can be seen in several of the pieces.

The flexibility shown by these crystals is not the effect of translation. Translation may be said to have taken place when "the particles have evidently slipped without change in orientation . . . there is no change in the direction of the optic axis" (for ice, e. g.).[a] If we assume the bending of a montroydite crystal to be the effect of translation, then, as each unit has simply slipped or moved parallel to itself, the resultant structure must have the same optic relation that obtained before bending, and the entire crystal will extinguish at the same time. But these bent crystals of montroydite do not show such extinction. The direction of extinction in such a bent crystal is always parallel to the edges of the crystal, and this extinction direction has therefore been bent with the crystal.

Moses gives the hardness as less than 2, but no trouble was experienced in scratching gypsum with montroydite. Its hardness is therefore placed between 2 and 3.

DENSITY.

The specific gravity was not determined by the writers, as they were unable to obtain any quantity of montroydite sufficiently free from mercury for the purpose. A determination on an amount of less than a gram can have but an approximate value, and it was found that almost all the montroydite contained inclusions of mercury, which would of course cause a material plus error. The value was also not determined by Moses, and therefore remains an unknown quantity.

LUSTER, COLOR, ETC.

The luster is very vitreous and often inclines to adamantine, as with all of these mercury minerals. No indications of greasy luster were seen.

The large crystals are in color a red, resembling that of some massive realgar and also vanadinite. It is a deep red with some brown in it. The smaller crystals are more of a dark orange or brownish-red, while the very minute ones, such as form the irregular-shaped masses or worms, are decidedly brown. Some of the more massive crystalline forms of montroydite are very dark, nearly black, though this may possibly be a secondary effect due to laboratory gases. In transmitted light the thicker crystals are of a beautiful deep orange-red, slightly pleochroic, in some directions tending more toward a

[a] Moses, A. J., Characters of crystals, p. 191.

reddish, normal to this tending to a yellowish shade. In thinner crystals the color becomes orange and in very thin plates is pale yellow, in which no pleochroism can be detected. The streak is yellow-brown, with no indication of any red color.

OPTICAL PROPERTIES.

Unfortunately it was not possible to obtain any data of value in regard to the optical constants. None of the crystals possess any natural prismatic edges that are suitable for a determination of the indices of refraction, and the flexibility of the mineral with its perfect cleavage prevents the preparation of artificial prisms. The mineral has parallel extinction and is slightly pleochroic in thick sections. The cleavage face seems to show the emergence of a bisectrix with a very large optic angle (much larger than 90°, even in oil). The trace of the axial plane is vertical, and therefore the axial plane would be parallel to (100) with bisectrices emerging on (001) and (010), probably $B_{x_0} \perp$ (010). It was not found feasible to measure any axial angle. Attempts were made to measure the indices of refraction by the method of the Duc de Chaulnes, using the microscope, but no concordant results were obtained, though the values were always considerably above 2.

CHEMISTRY.

Montroydite is completely volatile without fusing, yielding in a closed tube a sublimate of mercury only.

Since the oxygen as given for montroydite in the paper by Moses was assumed by difference, it seemed desirable to make a gas-volumetric determination of it by dissociating the mineral in vacuo in a tube with a plug of gold leaf near the exit, attached to a Töpler pump, collecting the gaseous product, measuring its volume, and testing it as to its chemical behavior. The gas contained nothing absorbable by caustic alkali and was wholly absorbed by yellow phosphorus. Hence it was pure oxygen, and the test confirmed the supposition of Moses. Analysis of 0.2213 gram of the prismatic needles gave the following results:

Analysis of montroydite compared with theoretical composition.

	Theory.	Found.
Hg.....	92.59	[a] 92.74
O......	7.41	[b] 7.49
	100.00	100.23

[a] Weighed as metal.
[b] Calculated from the volume.

CRYSTALLOGRAPHY.

GENERAL DESCRIPTION.

The crystallography of montroydite was so well described by Moses that only such additional and more accurate data as can naturally be obtained from a larger quantity and better material than was at his disposal are here presented. The results obtained by Moses were deduced from the measurement of a single crystal, which showed the mineral to be orthorhombic with 11 forms. The orientation chosen by Moses could not be improved upon, and is therefore retained.

Twenty-four crystals were measured by the writer, and many more were carefully examined with a hand lens; but it is believed that all the essential features of the crystallography of montroydite are embodied in the 24 crystals selected and measured. The result of this more extensive work has naturally increased the number of forms for montroydite. In addition to the 11 forms described by Moses, 45 new ones were measured, increasing the number to 56. The better crystals also allowed a more accurate determination of the crystal elements, which, however, show only a slight variation from the values obtained by Moses. The size of the crystals measured is shown in the following table, the smaller values (less than 1 millimeter) being only approximate:

Habit and dimensions of montroydite crystals.

Crystal No.	Habit.	Dimensions (millimeters).
1–4..	Very minute, long prismatic.........	Less than 1 mm. long.
5....	Long prismatic......................	3 by ¼ by ⅓.
6....	.....do.............................	1 by ⅕ by ⅕.
7....	.....do.............................	1 by ⅕ by ⅕.
8....	.....do.............................	14 by 1 by 1.
9....	Equidimensional.....................	1½ by 1½ by 1.
10....	.....do.............................	2 by 1½ by 1½.
11....	Short prismatic.....................	1 by ½ by ⅓.
12....	.....do.............................	3 by 2 by 2.
13....	.....do.............................	2 by 1 by 1.
14....	Long prismatic......................	4 by ⅓ by ⅓.
15....	Short prismatic.....................	3 by 1 by 1.
16....	Equidimensional.....................	2 by 1½ by 1½.
17....	.....do.............................	1½ by 1½ by 1½.
18....	Long prismatic......................	4 by ¼ by ¼.
19....	Short prismatic.....................	3½ by 1 by 1.
20....	.....do.............................	3 by 1 by 1.
21....	.....do.............................	3 by 1 by ½.
22....	Equidimensional.....................	1½ by 1 by 1.
23....	Distorted flat......................	4 by 1½ by 1⅓.
24....	Long prismatic, with equidimensional scepter crystal.	12 by 1½ by ⅔.

CALCULATION OF ELEMENTS.

In the calculation of the axial elements, values for p_0 are obtained from the measurements on the macrodomes, while values for q_0 are obtained from measurements of the brachydomes. From the pyramids values for both p_0 and q_0 are obtained. The best measurements of the unit prism faces gave the following values:

Measurements of ϕ for unit prism, montroydite.

Excellent reflection.	Good reflection.	Fair reflection.
° ′	° ′	° ′
57 28	56 26	57 27
29	27	31
27	27	25
29	30	27
33	26	27
25	26	27
27	28	32
30	30	29
26	32	
25	31	
31		
27		
29		
28		
34		
Av. 57 28.5	Av. 57 28.6	Av. 57 28.1

The average of all with due weight according to quality of reflection gives:

$$\phi = 57° \ 28.5'.$$
$$a = .63768.$$

This value is verified by measurement of the unit pyramids, the ϕ angle of which is the same as the ϕ angle for the unit prism, the following values for ϕ being obtained:

Measurements of ϕ for unit pyramids, montroydite.

Form.	No. of measurements.	Average value.
		° ′
331	11	57 29
221	13	26
111	16	31
112	14	28
Average	54	57 28.6

In calculating p_o and q_o from the different pyramids, a value is used for ϕ which is the average of the measurements and that obtained by calculation from ϕ (110) = 57° 28.5′, for in this way a better value can be obtained, since the final result will be the average of a greater number of measurements.

The value used for the ϕ angle for the unit pyramids is 57° 28.5′.

Values of ϕ angle for pyramids used in calculation of elements, montroydite.

	° ′
Pyramids of zone (130):(001):	
Average of 32 measurements of ϕ	27 35.5
Calculated from ϕ (110)=57° 28.5′	27 35.9
Value used in the calculation	27 35.7
Pyramids of zone (120):(001):	
Average of 22 measurements of ϕ	38 08.7
Calculated from ϕ (110)=57° 28.5′	38 05.9
Value used in the calculation	38 07.3
Pyramids of zone (210):(001):	
Average of 16 measurements of ϕ	72 19.7
Calculated from ϕ (110)=57° 28.5′	72 19.0
Value used in the calculation	72 19.4
Pyramids of zone (310):(001):	
Average of 8 measurements of ϕ	77 58.8
Calculated from ϕ (110)=57° 28.5′	78 00.0
Value used in the calculation	77 59.4

Calculation of p_o and q_o, montroydite crystals.

Form.	No. of measurements.	Angle.		Value.	
		ϕ	ρ	p_o	q_o
		° ′	° ′		
012	28	0 00	30 55.0	....	1.1978
023	10	0 00	38 40.5	....	1.2006
102	14	90 00	43 12.7	1.8789	....
101	23	90 00	61 59.5	1.8801	....
302	9	90 00	70 27.1	1.8778	....
201	14	90 00	75 02.9	1.8723	....
301	21	90 00	79 57.7	1.8831	....
112	23	57 28.5	48 04.6	1.8780	1.1975
111	54	57 28.5	65 49.3	1.8781	1.1976
221	32	57 28.5	77 20.4	1.8767	1.1967
331	31	57 28.5	81 29.2	1.8775	1.1972
133	6	27 35.7	53 30.5	1.8785	1.1981
132	25	27 35.7	63 47.1	1.8816	1.2000
122	24	38 07.3	56 45.0	1.8832	1.1999
211	18	72 19.4	75 43.9	1.8731	1.1940
311	9	77 59.4	80 07.3	1.8724	1.1951

The average of 303 measurements of p_0 is 1.8788; the average of 260 measurements of q_0 is 1.1977. The elements for montroydite are therefore:

$$
\begin{aligned}
a &= .6375 \\
c &= 1.1977 \\
(010):(110) &= 57^\circ\,29' \\
(001):(011) &= 50^\circ\,08' \\
(001):(101) &= 61^\circ\,59'
\end{aligned}
$$

Comparison of measured angles with those calculated from the foregoing values.

Angle.	Average measured value.		Calculated value.		Difference.	
	°	′	°	′	°	′
ϕ (110)	57	29	57	29	0	00
ϕ (11l)	57	29	57	29	0	00
ϕ (13l)	27	36	27	36	0	00
ϕ (12l)	38	09	38	06	+0	03
ϕ (21l)	72	20	72	19	+0	01
ϕ (31l)	77	59	78	00	−0	01
ρ (012)	30	55	30	55	0	00
ρ (023)	38	41	38	36	+0	05
ρ (102)	43	13	43	13	0	00
ρ (101)	62	00	61	59	+0	01
ρ (302)	70	27	70	28	−0	01
ρ (201)	75	03	75	06	−0	03
ρ (301)	79	58	79	56	+0	02

The values obtained by Moses, namely, $a = 0.63797$ and $c = 1.1931$, are very close to the above.

FORMS AND ANGLES.

Eleven forms were determined by Moses, all of which were found by the writer and all of which are common forms for montroydite. In addition to these 11 forms, 45 new ones were found, making a total of 56 for the mineral.[a]

The 11 forms found by Moses are:

a {100}	*s* {112}	*t* {122}
b {010}	*o* {111}	*r* {211}
m {110}	*x* {331}	*w* {311}
d {101}	*e* {132}	

The new forms can be seen in the following table, which gives all the forms for montroydite, their letters and the average of the measured angles compared with those calculated from the elements derived by the writer. The new forms are starred.

[a] A number of minute faces gave poor reflections, measurements of which varied considerably and agreed only approximately for the forms {356}, {214}, {212}, {423}, and {312}. These can not, however, be classed even as doubtful, as their characters were too uncertain.

Forms and angles on montroydite crystals.

No.	Letter.	Symbol.		Measured.		Calculated.	
		Gdt.	Miller.	ϕ	ρ	ϕ	ρ
				° ′	° ′	° ′	° ′
1	*a*	$\infty 0$	100	90 00	90 00	90 00	90 00
2	*b*	0∞	010	0 00	90 00	0 00	90 00
3	**l*	$\infty 10$	1. 10 0	8 52	90 00	8 55	90 00
4	**h*	$\infty 2$	120	37 58	90 00	38 06	90 00
5	**k*	$\infty \frac{5}{3}$	350	43 36	90 00	43 17	90 00
6	**C*	$\infty \frac{3}{2}$	230	46 13	90 00	46 17	90 00
7	*m*	∞	110	57 29	90 00	57 29	90 00
8	**f*	$\frac{3}{2} \infty$	320	66 29	90 00	66 59	90 00
9	*ξ	3∞	310	77 50	90 00	78 00	90 00
10	**j*	4∞	410	80 56	90 00	80 57	90 00
11	*Φ	5∞	510	82 34	90 00	82 44	90 00
12	**v*	$0\frac{1}{2}$	012	0 00	30 55	0 00	30 55
13	**y*	$0\frac{2}{3}$	023	0 00	38 41	0 00	38 36
14	**K*	$0\frac{4}{5}$	045	0 00	43 22	0 00	43 47
15	**z*	01	011	0 00	50 31	0 00	50 08
16	**G*	$0\frac{3}{2}$	032	0 00	60 57	0 00	60 54
17	**L*	02	021	0 00	67 46	0 00	67 20
18	*β	06	061	0 00	81 56	0 00	82 05
19	**E*	$\frac{1}{3}0$	103	90 00	31 31	90 00	32 04
20	**g*	$\frac{1}{2}0$	102	90 00	43 13	90 00	43 13
21	**M*	$\frac{2}{3}0$	203	90 00	51 51	90 00	51 24
22	*d*	10	101	90 00	62 00	90 00	61 59
23	**n*	$\frac{3}{2}0$	302	90 00	70 27	90 00	70 28
24	**q*	20	201	90 00	75 03	90 00	75 06
25	*μ	30	301	90 00	79 58	90 00	79 56
26	*α	$\frac{1}{3}1$	133	27 30	53 31	27 36	53 30
27	*ζ	$\frac{2}{5}\frac{6}{5}$	265	27 39	59 22	27 36	58 21
28	*e*	$\frac{1}{2}\frac{3}{2}$	132	27 37	63 47	27 36	63 45
29	**N*	$\frac{2}{3}2$	263	28 05	69 15	27 36	69 42
30	**Z*	$\frac{1}{2}\frac{7}{6}$	376	33 38	59 21	33 55	59 18
31	*t*	$\frac{1}{2}1$	122	38 09	56 45	38 06	56 42
32	**O*	$\frac{2}{3}\frac{4}{3}$	243	38 55	64 13	38 06	63 46
33	**Q*	$\frac{2}{9}\frac{1}{3}$	239	46 58	29 32	46 17	30 01
34	**S*	$1\frac{3}{2}$	232	47 05	68 59	46 17	68 58
35	**R*	$\frac{1}{2}\frac{2}{3}$	346	49 32	51 14	49 38	50 57
36	**U*	$\frac{3}{4}1$	344	50 14	61 10	49 38	61 36
37	**A*	$\frac{1}{4}$	114	57 36	29 06	57 29	29 07
38	**B*	$\frac{1}{3}$	113	57 38	35 49	57 29	36 36
39	*s*	$\frac{1}{2}$	112	57 29	48 05	57 29	48 05
40	**D*	$\frac{2}{3}$	223	57 37	55 15	57 29	56 03
41	*o*	1	111	57 29	65 49	57 29	65 50
42	**i*	2	221	57 29	77 20	57 29	77 21
43	*x*	3	331	57 29	81 29	57 29	81 29
44	*δ	5	551	57 30	84 38	57 29	84 52
45	**V*	$\frac{1}{2}\frac{2}{5}$	5. 4. 10	62 33	47 08	62 59	46 32
46	*γ	$\frac{5}{2}2$	542	62 40	80 22	62 59	79 16
47	**P*	$\frac{1}{2}\frac{1}{3}$	326	66 22	45 42	66 58	45 34
48	*π	$1\frac{2}{3}$	323	66 46	63 53	66 58	63 54
49	*r*	21	211	72 20	75 44	72 19	75 46
50	*ϕ	$3\frac{3}{2}$	632	71 43	80 23	72 19	80 24

Forms and angles on montroydite crystals—Continued.

No.	Letter.	Symbol.		Measured.		Calculated.	
		Gdt.	Miller.	ϕ	ρ	ϕ	ρ
				° ′	° ′	° ′	° ′
51	*ρ	$\frac{7}{13}\frac{3}{13}$	7.3.13	74 29	46 29	74 43	46 22
52	*λ	$\frac{3}{7}\frac{1}{7}$	317	78 26	39 52	78 00	39 27
53	*Δ	$1\frac{1}{3}$	313	78 22	63 00	78 00	62 29
54	w	31	311	77 59	80 07	78 00	80 09
55	*W	41	411	80 47	82 45	80 57	82 31
56	*ω	$\frac{5}{6}\frac{1}{12}$	10.1.12	86 21	57 21	86 21	57 28

The following pages give a more detailed description of the forms observed on montroydite. For convenience they have been divided into three groups: (a) The common forms, which include those that were observed 10 or more times and, excepting {10.1.12}, were noticed on 8 or more crystals; (b) those that were measured less than 10 times but at least 3 times; and (c) those that were found only once or twice. This last group constitutes the class of rare forms. The number of forms in each of these groups was: Common forms (a), 22; less common forms (b), 18; rare forms (c), 16; making the total number of forms 56.

DESCRIPTION OF COMMON FORMS.

The following table shows the measurements with the occurrence of the common forms, except a, b, and m,[a] for which the measurements are not given.

Measurements of common forms on montroydite crystals.

Letter.	Symbol.	Number of crystals.	Number of faces measured.	Measured.		Calculated.		Number measured within 5′.		Limits of measurement.	
				ϕ	ρ	ϕ	ρ	ϕ	ρ	ϕ	ρ
				° ′	° ′	° ′	° ′			° ′ ° ′	° ′ ° ′
*v	012	18	39	0 00	30 55	0 00	30 55	......	21	....	30 48 31 00
*y	023	11	17	0 00	38 41	0 00	38 36	......	2	....	38 22-39 00
*z	011	10	12	0 00	50 31	0 00	50 08	......	1	....	48 45 51 56
*g	102	15	24	90 00	43 13	90 00	43 13	......	11	....	42 59-43 48
d	101	23	45	90 00	62 00	90 00	61 59	......	30	....	61 28-62 06
*n	302	8	10	90 00	70 27	90 00	70 28	......	6	....	70 08-70 41
*q	201	13	21	90 00	75 03	90 00	75 06	......	8	....	74 47-75 38
*u	301	14	46	90 00	79 58	90 00	79 56	......	15	....	79 48-80 21
*a	133	10	12	27 30	53 31	27 36	53 30	3	4	27 03-28 48	52 58 54 22
e	132	16	33	27 37	63 47	27 36	63 45	11	12	27 20-28 20	63 05-64 30
t	122	20	45	38 09	56 45	38 06	56 42	15	13	37 04-39 01	56 14-57 53
s	112	22	72	57 29	48 05	57 29	48 05	......	24	....	47 44-48 46
o	111	23	84	57 29	65 49	57 29	65 50	......	40	....	65 30 66 00
*i	221	21	48	57 29	77 20	57 29	77 21	......	21	....	77 01-78 18
x	331	17	52	57 29	81 29	57 29	81 29	......	24	....	80 31-81 54
r	211	16	24	72 20	75 44	72 19	75 46	11	10	71 31-72 41	75 15-75 57
*ρ	7.3.13	9	19	74 29	46 29	74 43	46 22	8	8	73 19-75 48	45 46-47 23
w	311	8	13	77 59	80 07	78 00	80 09	3	6	77 43-78 39	79 50-80 25
*ω	10.1.12	4	11	86 21	57 21	86 21	57 28	1	3	85 00-86 56	56 55-57 58

[a] See p. 57 for measurements of m.

Occurrence and measurements of the form ρ {7.3.13} (new) on montroydite crystals.

Crystal No.	Reflection.	Size of face.	ϕ (74° 43′ calc.).		ρ (46° 22′ calc.).	
			°	′	°	′
8	Fair.....	Small...........	74	36	46	21
8	Poor	Small...........	74	42	46	27
9	Fair.....	Medium........	74	33	46	21
10	Good....	Medium........	74	35	46	26
10	Fair.....	Medium........	74	49	46	29
11	Fair.....	Medium........	73	19	45	46
11	Fair.....	Large...........	75	00	46	45
11	Poor	Minute..........	73	56	46	26
15	Poor	Line face	73	40	46	17
15	Poor	Small...........	73	40	46	05
16	Fair.....	Medium........	74	48	46	29
16	Fair.....	Medium........	74	23	46	29
17	Good....	Medium........	74	51	46	27
17	Fair.....	Medium........	74	31	46	40
20	Fair.....	Large...........	74	45	46	18
22	Fair.....	Medium........	74	38	46	37
22	Fair.....	Medium........	74	20	46	42
22	Fair.....	Small..........	74	12	46	43
22	Poor	Small...........	75	48	47	23

ω{10.1.12}.—The size of this form varies from a line face to one of small size, yet larger than many of the other forms. It is near to the unit dome {101} and lies in the zone {7.3.13} : {101}.

Occurrence and measurements of the form ω{10.1.12} (new) on montroydite crystals.

Crystal No.	Reflection.	Size of face.	ϕ (86° 21′ calc.).		ρ (57° 28′ calc.).	
			°	′	°	′
11	Poor.....	Line face.......	86	22	57	28
11	Poor.....	Line face.......	85	28	57	29
17	Fair	Line face.......	86	34	56	55
17	Poor.....	Line face.......	86	56	57	18
17	Fair	Medium........	86	50	57	58
17	Fair	Medium........	85	02	57	11
20	Poor.....	Small	85	00	57	10
22	Poor.....	Line face.......	86	36	57	21
22	Poor.....	Line face.......	86	55	57	21
22	Fair	Line face.......	86	38	57	25
22	Poor.....	Small	87	28	57	12

The vicinal form {44.1.48} usually occurs with {10.1.12} and is commonly much larger than it, being present as large faces, most of which give a good signal. However, the complex indices permit the form to be classed only as vicinal.

DESCRIPTION OF LESS COMMON FORMS.

In the following table are given all the measurements, with descriptions, of those forms which were measured less than 10 times but more than twice, all being new forms. They constitute with the common forms the essential form system of montroydite.

Occurrence and measurements of less common forms on montroydite crystals.

[Bold-faced figures show calculated values.]

Form and crystal No.	Reflection.	Size of face.	φ	ρ
			° ′	° ′
l{1.10.0}.	....	....	**8 55**	....
6	Fair	Medium........	9 04	....
6	Fair	Small	8 54	....
6	Poor.....	Line face.......	9 06	....
14	Poor.....	Line face.......	8 42	....
17	Poor.....	Line face.......	7 43	....
20	Poor.....	Line face.......	9 40	....
h{120}.	....	....	**38 06**	....
12	Poor.....	Minute..........	36 43	....
15	Poor.....	Line face.......	37 59	....
21	Poor.....	Minute..........	39 12	....
k{350}.	....	....	**43 16**	....
4	Poor.....	Small	44 22	....
4	Fair	Small	43 20	....
4	Poor.....	Small...........	43 23	....
4	Poor.....	Small	43 19	....
ξ{310}.	....	....	**78 00**	....
14	Poor	Line face.......	78 12	....
19	Fair	Line face.......	77 54	....
19	Poor.....	Line face.......	77 25	....
j{410}.	....	....	**80 57**	....
6	Fair	Small	80 55	....
6	Fair	Small	80 59	....
19	Poor.....	Line face.......	80 55	....
θ{510}.	....	....	**82 44**	....
6(?)	Poor.....	Line face.......	82 03	....
22	Poor.....	Line face.......	82 17	....
22	Poor.....	Line face.......	82 51	....
K{045}.	....	....	....	**43 47**
16	Poor.....	Line face.......	....	43 00
20	Poor.....	Line face.......	....	43 47
24	Poor.....	Line face.......	....	43 19

Occurrence and measurements of less common forms on montroydite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
L{021}.	....	....	....	**67 20**
16	Poor.....	Line face......	....	68 58
17	Fair.....	Small..........	....	69 14
20	Poor.....	Line face......	....	67 24
21	Poor.....	Minute.........	....	66 22
24	Poor.....	Line face......	....	66 50
β{061}.	....	....	....	**82 05**
2	Fair.....	Medium.........	....	81 57
2	Fair.....	Medium.........	....	82 00
2	Fair.....	Medium.........	....	82 06
17	Fair.....	Small..........	....	81 42
E{103}.	....	....	....	**32 04**
6	Poor.....	Minute.........	....	31 52
6	Poor.....	Line face......	....	31 33
9	Poor.....	Minute.........	....	31 08
M{203}.	....	....	....	**51 24**
10	Poor.....	Minute.........	....	51 10
10	Poor.....	Line face......	....	51 50
17	Poor.....	Line face......	....	52 32
N{263}.	....	....	**27 36**	**69 42**
17	Poor.....	Small..........	28 42	69 41
21	Fair.....	Small..........	27 47	69 57
21	Poor.....	Minute.........	27 47	68 06
Z{376}.	....	....	**33 55**	**59 18**
6	Fair.....	Line face......	31 48	58 50
9	Poor.....	Line face......	34 29	59 03
16	Poor.....	Line face......	34 57	59 26
16	Poor.....	Line face......	33 33	59 15
22	Poor.....	Line face......	33 24	60 10
A{114}.	....	....	**57 29**	**29 07**
2	Poor.....	Minute.........	57 54	29 10
6	Poor.....	Small..........	57 34	29 10
8	Poor.....	Small..........	57 29	28 23
8	Poor.....	Line face......	55 52	28 51
16	Poor.....	Minute.........	57 27	30 17
20	Poor.....	Small..........	57 37	29 25
20	Poor.....	Minute.........	57 37	28 24

Occurrence and measurements of less common forms on montroydite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
B {113}.	....	....	**57 29**	**36 36**
2	Poor.....	Minute.........	57 54	35 16
21	Poor.....	Minute.........	57 33	38 21
22	Poor.....	Line face......	57 28	33 51
D {223}.	....	....	**57 29**	**56 03**
6	Poor.....	Line face......	57 37	55 50
6	Poor.....	Line face......	57 37	55 56
8	Poor.....	Line face......	57 29	55 51
12	Poor.....	Line face......	57 27	54 10
18	Poor.....	Minute.........	56 07	54 19
22	Poor.....	Small..........	57 28	55 25
δ {551}.	....	....	**57 29**	**84 52**
2(?)	Poor.....	Minute.........	54 34	84 00
9	Poor.....	Line face......	57 26	85 03
20	Poor.....	Line face......	57 35	85 16
22	Poor.....	Line face......	57 28	84 14
P {326}.	....	....	**66 58**	**45 34**
6	Poor.....	Minute.........	66 30	45 54
6	Poor.....	Small..........	63 59	45 14
6	Fair.....	Small..........	67 49	45 19
8	Poor.....	Line face......	64 37	46 05
17	Poor.....	Line face......	67 50	47 52
22	Poor.....	Minute.........	67 06	44 20
24	Poor.....	Line face......	66 40	45 12
{44.1.48}[a]	....	....	**89 10**	**59 46**
17	Fair.....	Small..........	88 45	59 40
18	Poor.....	Minute.........	88 15	59 53
22	Good....	Medium........	89 10	59 46
22	Fair.....	Medium........	89 17	59 49
22	Poor.....	Small..........	89 04	59 47
22	Poor.....	Small..........	89 09	59 48

[a] Vicinal form. This form lies nearly in the zone {7.3.13}:{101}, which has the zone symbol [12$\bar{1}$]:

$$\begin{array}{r} 1\ \ 2\ \ \bar{1} \\ 44.1.48 \\ \hline \Sigma+=46 \\ \Sigma-=48 \end{array}$$

The one face giving a good reflection agrees exactly in angles with the calculated values.

DESCRIPTION OF RARE FORMS.

The following table gives all the measurements for each of the rare forms:

Occurrence and measurements of rare forms, montroydite crystals.

Letter.	Symbol.	Crystal No.	Reflection.	Size of face.	Measured.		Calculated.	
					ϕ	ρ	ϕ	ρ
					° ′	° ′	° ′	° ′
C	230	21	Poor...	Line face.....	46 13	90 00	46 17	90 00
f	320	6	Poor...	Line face.....	66 45	90 00	66 58	90 00
f	320	6	Poor...	Line face.....	66 12	90 00	66 58	90 00
G	032	6	Poor...	Small.........	0 00	62 02	0 00	60 54
G	032	6	Poor...	Small.........	0 00	59 52	0 00	60 54
ζ	265	21	Poor...	Minute........	27 41	59 22	27 36	58 21
ζ	265	21	Poor...	Line face......	27 37	59 22	27 36	58 21
δ	[a] 243	17	Poor...	Line face......	38 55	64 13	38 06	63 46
Q	239	17	Poor...	Small..........	46 58	29 32	46 17	30 01
S	232	22	Poor...	Minute........	47 05	68 59	46 17	68 58
R	346	6	Poor...	Line face......	48 55	50 59	49 38	50 57
R	346	11	Poor...	Line face......	50 09	51 29	49 38	50 57
M	344	11	Poor...	Minute........	50 14	61 10	49 38	61 36
V	5. 4. 10	3	Poor...	Minute........	62 26	47 33	62 59	46 32
V	5. 4. 10	15	Poor...	Line face......	62 40	46 42	62 59	46 32
γ	[b] 542	21	Poor...	Line face......	62 40	80 22	62 59	79 16
π	323	6	Fair...	Line face......	66 46	63 53	66 58	63 54
ϕ	632	22	Poor...	Minute........	71 26	80 57	72 19	80 24
ϕ	632	24	Poor...	Minute........	72 00	79 49	72 19	80 24
λ	317	17	Fair...	Small..........	78 26	39 52	78 00	39 27
Δ	313	12	Poor...	Minute........	78 22	63 00	78 00	62 29
W	[c] 411	18	Poor...	Line face......	81 31	82 51	80 57	82 31
W	[c] 411	18	Poor...	Line face......	80 02	82 39	80 57	82 31

[a] The face lies in the zone with {263} and {010}.
[b] This form lies in the zone of and between {2$\bar{1}$1} and {331}.
[c] Two line faces between {301} and {110}, and {$\bar{3}$01} and {1$\bar{1}$0}.

SUMMARY OF FORMS.

The forms for montroydite may conveniently be repeated here at the close of the foregoing descriptions:

(*a*) *Common forms.*

a(100)	*n*(302)	*i*(221)
b(010)	*q*(301)	*x*(331)
m(110)	*u*(301)	*r*(211)
v(012)	α(133)	ρ(7. 3. 13)
y(023)	*e*(132)	*w*(311)
z(011)	*t*(122)	ω(10. 1. 12)
g(102)	*s*(112)	
d(101)	*o*(111)	

(*b*) *Less common forms.*

l(1. 10. 0)	*K*(045)	*Z*(376)
h(120)	*L*(021)	*A*(114)
k(350)	β(061)	*B*(113)
ξ(310)	*E*(103)	*D*(223)
j(410)	*M*(203)	δ(551)
[illegible](510)	*N*(263)	*P*(326)

(*c*) *Rare forms.*

C(230)	*S*(232)	ϕ(632)
f(320)	*R*(346)	λ(317)
G(032)	*M*(344)	Δ(313)
ζ(265)	*V*(5. 4. 10)	*W*(411)
O(243)	γ(542)	
Q(239)	π(323)	

DISCUSSION OF FORMS.

Prism zone (*No. 1*)[a]; *symbol*, $\frac{h}{k}$.

Form.....	*b*	*l*	*h*	*k*	*C*	*m*	*f*	ξ	*j*	[illegible]	*a*
	010	1. 10. 0	120	350	230	110	320	310	410	510	100
Symbol...	0	1/10	1/2	3/5	2/3	1	3/2	3	4	5	∞
N_3........	0	(1/10) .	1/2	(3/5)	2/3	1	3/2 .	3	(4)	(5)	∞

The two forms {130} and {210} are lacking to make the series N_3 complete. Four forms are extra. One of them, 3/5 or {350}, is interesting, as it was noticed on only one crystal (No. 4), on which, however, all four faces of the form occur. The crystal is broken at both ends, and *a*, *b*, *k*, and *m* are the only forms present. The three other extra forms, {1.10.0}, {410}, and {510} are well established, all occurring on more than one crystal. As these four forms do not belong to the normal series N_3, special attention is called to them by the discussion, but a due consideration of all facts shows that there is no reason for excluding or considering any of them as doubtful. The conclusion then follows that this prism zone is somewhat disturbed, and it is to be specially noticed that most of the forms causing this disturbance are nearest to the forms with the simplest indices in the entire zone. Thus {1.10.0} is nearest {010}; {410} and {510} are nearest {100}. The form {350} is not closest to the next simplest form, which would be {110}, but it is next to {120}, which is also a simple form. This zone therefore supports the statement, which is verified by the further discussions, that the forms which do not fit in the normal series—that is, those which cause a disturbance in an otherwise normal zone—are usually nearest to the forms with simplest indices.

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[a] See gnomonic projection (Pl. IV) for reference to zone number.

Brachydome zone (No. 2); symbol, $\frac{k}{l}$.

Form	c[a] 001	v 012	y 023	K 045	z 011	G 032	L 021	β 061	b 010
Symbol	0	1/2	2/3	4/5	1	3/2	2	6	∞
N_3	0	. 1/2	2/3	(4/5)	1	3/2	2 .	(6)	∞

Here again we have two extra forms, {045} and {061}, both of which are well established. These extra forms also are nearest the normal forms with simplest indices; thus {045} is nearest {011} and {061} is nearest {010}.

Macrodome zone (No. 3); symbol, $\frac{h}{l}$.

Form	c[a] 001	E 103	g 102	M 203	d 101	n 302	q 201	u 301	a 100
Symbol	0	1/3	1/2	2/3	1	3/2	2	3	∞
N_3	0	1/3	1/2	2/3	1	3/2	2	3	∞

This zone is entirely normal, there being neither missing,[a] extra, nor disagreeing forms. It may be remarked that most of the non-accordances for montroydite crystals are instances of either missing or extra forms; very few are disagreements with the members of the normal series.

Zone $\frac{h}{l}=\frac{1}{2}$*(No. 4); symbol,* $\frac{k}{l}$.

Form	g 102	P 326	V 5.4.10	s 112	R 346	t 122	Z 376	e 132	b 010
Symbol	0	1/3	2/5	1/2	2/3	1	7/6	3/2	∞

Dividing the series at 1, and letting v in any row represent the member in the preceding line, we have:

v	0	1/3	2/5	1/2	2/3	1
$\frac{v}{1-v}$	0	1/2	2/3	1	2	∞
N_3	0 .	1/2	2/3	1 .	2 .	∞

v	1	7/6	3/2	∞
$v-1$	0	1/6	1/2	∞
$2v$	0	1/3	1	∞
N_1	0	(1/3)	1	∞

In the first division, the zone is normal. In the second, only 1/3 or {376} is extra.

Zone $\frac{h}{l}=\frac{2}{3}$*(No. 5); symbol,* $\frac{k}{l}$.

Form	M 203	D 223	O 243	N 263	b 010
Symbol	0	2/3	4/3	2	∞
$\frac{3v}{4}$	0	1/2	1	3/2	∞
N_2	0	1/2	1	[3/2]	∞

We would expect 2 in place of 3/2, which would give the form {483}, but {263} are the correct symbols.

[a] The form c{001} is not present on these crystals, but is here introduced in order to simplify the discussion.

Zone $\frac{h}{l}=1$ *(No. 6); symbol,* $\frac{k}{l}$.

Form	*d*	*Δ*	*π*	*o*	*S*	*b*
	101	313	323	111	232	010
Symbol	0	1/3	2/3	1	3/2	∞
N_3	0	1/3 .	2/3	1	3/2 . .	∞

The zone is normal, though incomplete.

Zone $\frac{h}{l}=3$ *(No. 7); symbol,* $\frac{k}{h}$.

Form	*u*	*w*	*φ*	*x*	*b*
	301	311	632	331	010
Symbol	0	1/3	1/2	1	∞
2*v*	0	2/3	1	2	∞
N_2	0	[2/3]	1	2	∞

The form 2/3 or {311} is a common one for montroydite.

Zone $\frac{k}{l}=1$ *(No. 8); symbol,* $\frac{h}{l}$.

Form	*z*	*α*	*t*	*U*	*o*	*r*	*w*	*W*	*a*
	011	133	122	344	111	211	311	411	100
Symbol	0	1/3	1/2	3/4	1	2	3	4	∞
N_3	0	1/3	1/2	[3/4]	1 .	2	3	(4)	∞

In place of 3/4, we would expect 2/3 or {233}. Measurements show that {344} are the correct indices. *W* {411} is extra. Both forms, however, are well established.

Note again that 3/4 or {344} is nearest 1 or {111} and 4 or {411} is nearest to ∞ or {100}.

Zone $\frac{k}{l}=2$ *(No. 9); symbol,* $\frac{h}{l}$.

Form	*L*	*N*	*i*	*γ*	*a*
	021	263	221	542	100
Symbol	0	2/3	2	5/2	∞
$\frac{v}{2}$	0	1/3	1	5/4	∞

This zone is abnormal. Of these forms, *γ* {542} should be confirmed.

Pyramid zone $\frac{h}{k}=1$ *(No. 10); symbol,* $\frac{h}{l}$.

Form	*c*	*A*	*B*	*s*	*D*	*o*	*i*	*x*	*δ*	*m*
	001	114	113	112	223	111	221	331	551	110
Symbol	0	1/4	1/3	1/2	2/3	1	2	3	5	∞
N_3	0	(1/4)	1/3	1/2	2/3	1 .	2	3	(5)	∞

The two forms {114} and {551} are extra, but both are well established. Again note that both are nearest the simplest forms.

Zone (201):(021) (No. 11); symbol, $\frac{h}{l}$.

Form	*m*	*w*	*q*	*o*	*O*	*e*	*L*
	110	311	201	111	243	132	021
Symbol	∞	3	2	1	2/3	1/2	0
N_3	∞	3	2 .	1	2/3	1/2 .	0

The zone is normal.

Zone (102):(011) (No. 12); symbol, $\frac{h}{l}$.

Form	*o* 1$\bar{1}$1	*g* 102	*λ* 317	*B* 113	*z* 011
Symbol	1	1/2	3/7	1/3	0
$\frac{2v}{1-v}$	∞	2	3/2	1	0
N_2	∞	2	(3/2)	1 .	0

Zone (001):(130) (No. 13); symbol, $\frac{h}{l}$.

Form	*c* 001	*a* 133	*ζ* 265	*e* 132	*N* 263
Symbol	0	1/3	2/5	1/2	2/3
$\frac{3}{2}v$	0	1/2	3/5	3/4	1
$\frac{v}{1-v}$	0	1	3/2	3	∞
N_2	0 .	1	(3/2) .	(3)	∞
or N_3	0 . . .	1	3/2 .	3	∞

Zone (012):(101) (No. 14); symbol, $\frac{h}{l}$.

Form	*v* 012	*B* 113	*ρ* 7.3.13	*ω* 10.1.12	*d* 101	*w* 3$\bar{1}$1	— (2$\bar{1}$0)
Symbol	0	1/3	7/13	5/6	1	3	∞
N_3	0	1/3	[7/13] .	(5/6)	1 . .	3	∞

The form {7.3.13} takes the place of the simpler form {214}, which was not observed on these crystals. The form {10.1.12} is extra, being very close to {101}. Both forms partake of a vicinal character, though they are included in the list of established forms on account of their relatively large size, good reflections, and frequent occurrence.

The following forms are extra to the normal series, and attention is again called to the fact that most of these extra forms, or forms which cause a disturbance in the otherwise normal series, are very close to the forms with simplest indices:

1.10.0, close to 010.	061, close to 010.
410, close to 100.	411, close to 100.
510, close to 100.	114, close to 001.
350, close to 120.	551, close to 110.
045, close to 011.	344, close to 111.

The following pyramids, which do not fit in well with the normal series, are not so close to simple forms:

376, near 122.	542, near 221.
263, near 121.	317, near 102.

Combinations of forms on montroydite crystals.

Letter.	Symbol.	Crystal No.—																							
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
a	100	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	?	a
b	010	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b
l	1.10.0						l								l			l			l				
h	120												h			h						h			
k	350				k																				
C	230																					C			
m	110	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
f	320						f																		
ξ	310														ξ					ξ					
j	410						j													j					
θ	510																						θ		
v	012			v		v	v		v	v	v	v	v	v	v	v	v	v		v	v	v	v		v
y	023	y					y			y		y	y	y			y	y			y		y		y
K	045																K				K				K
z	011	z	z				z		z				z				z	z		z	z	z			
G	032						G																		
L	021																L	L			L	L			L
β	061		β															β							
E	103						E			E															
g	102					g	g		g	g	g	g	g		g	g	g	g		g	g		g		g
M	203										M							M							
d	101	d	d	d		d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
n	302			n						n			n			n	n				n		n		n
q	201			q		q	q	q		q	q		q	q		q	q				q	q			q
u	301		u						u	u	u	u	u		u	u	u	u			u	u	u		u
α	133	α				α	α		α	α		α				α		α			α				α
ζ	265																					ζ			
e	132	e		e			e	e	e		e	e	e			e	e	e		e	e	e	e		e
N	263																	N				N			
Z	376						Z			Z							Z						Z		
t	122	t		t		t	t	t	t	t	t	t	t	t	t	t	t	t		t	t		t	t	t
O	243																	O							
Q	239																	Q							
S	232																						S		
R	346						R					R													
U	344											U													
A	114		A				A		A								A				A				
B	113		B																			B	B		
s	112	s	s	s		s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s		s	s	s
D	223						D		D				D						D				D		
o	111	o	o	o		o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
i	221	i	i	i		i	i	i	i	i		i	i	i	i	i	i	i		i	i	i	i	i	i
x	331	x		x		x	x	x	x	x		x	x			x	x	x	x	x	x	x	x		x
δ	551		δ							δ											δ		δ		
V	5.4.10			V												V									
γ	542																				γ				
P	326						P		P									P					P		P
π	323						π																		
r	211	r		r		r		r	r	r		r	r		r	r	r	r	r	r		r			r
φ	632																						φ		φ
ρ	7.3.13								ρ	ρ	ρ	ρ				ρ	ρ	ρ			ρ		ρ		
λ	317																	λ							
Δ	313												Δ												
w	311	w				w		w					w					w			w	w			w
W	411																		W						
ω	10.1.12											ω						ω			ω		ω		

ZONAL RELATIONS, STRIATIONS, AND GNOMONIC PROJECTION OF FORMS.

As can be seen by the discussion of the forms just given, montroydite crystals are very symmetrical, all of the forms found lying in well-developed zones, many of which show but a very slight disturbance. Intimately connected with these zone directions are the striations, which are well developed on some crystals. In all, six directions or zones of striations were noticed on these crystals. They are given below, in approximately the order of the greatest development of the striæ.

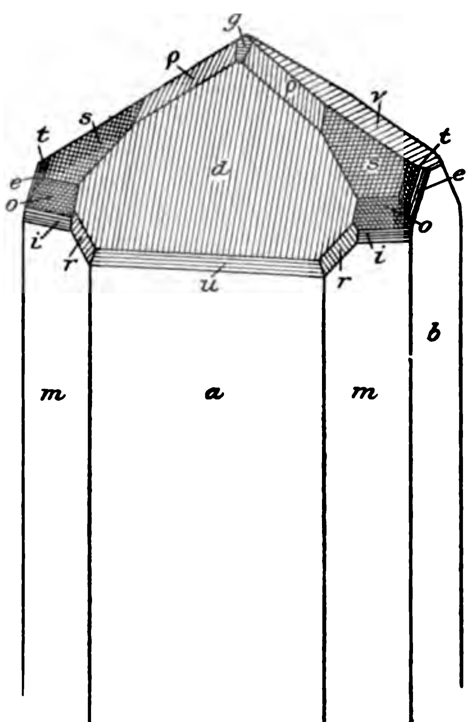
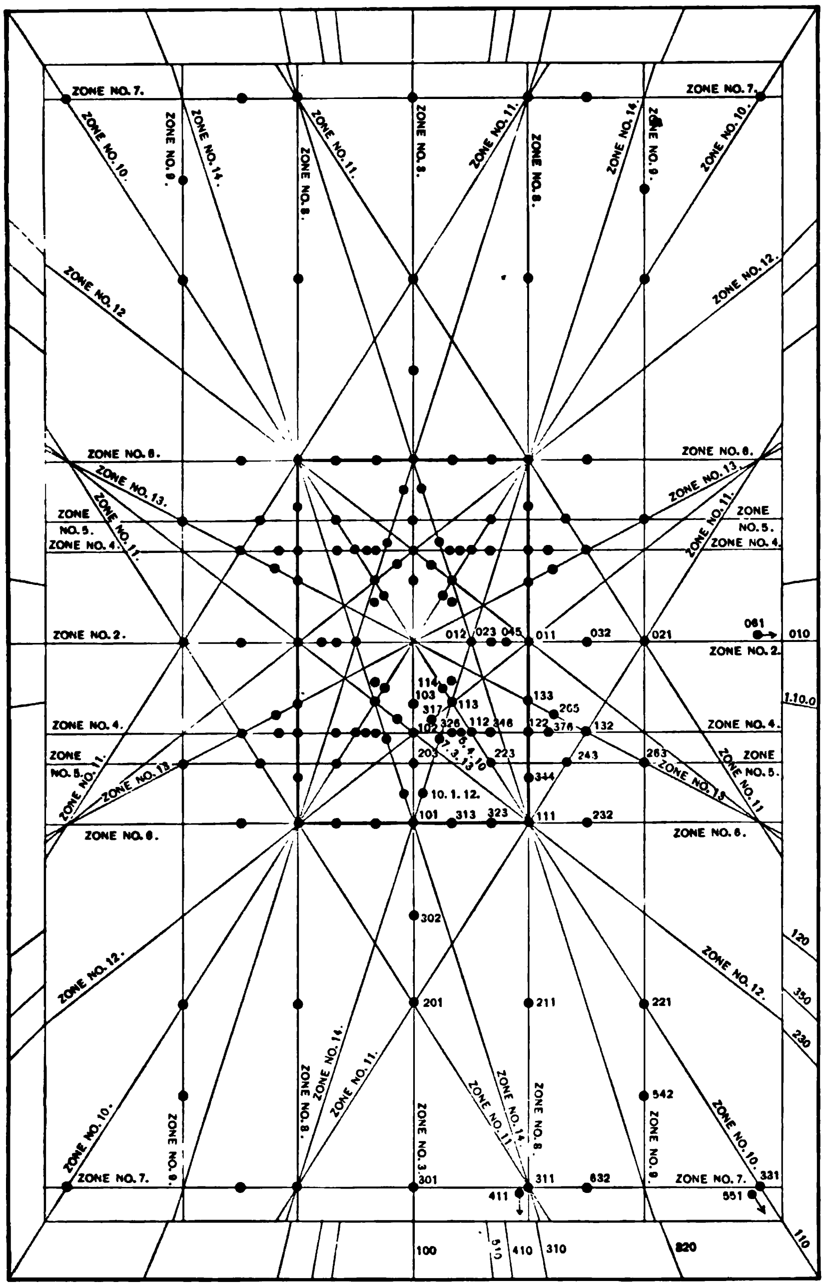


FIGURE 8.—Montroydite crystal showing striations.

(1) Zone (001) : (010). The clinodomes are all striated, but particularly the lower part of the prominent dome $v\{012\}$, which is usually present on these crystals as a large face. Between the lower end of v and $b\{010\}$, a rounded striated surface often takes the place of distinct faces, though it has been possible to establish the presence of six domes between v and b, namely: $y\,\{023\}$, $K\{045\}$, $z\{011\}$, $G\{032\}$, $L\{021\}$, and $\beta\{061\}$.

(2) Zone (102) : (112) : (010). This zone of pyramids almost always contains striated faces. The form $\rho\{7.3.13\}$ is almost in this zone, but, as can be seen on the crystals by means of the striæ, it is a little out. Two narrow faces of the zone (102) : (010) lie between (102) and (112), namely, $P(326)$ and $V(5.4.10)$, while between (112) and (010) are the two prominent forms $t\{122\}$ and $e\{132\}$, with the less common $R\{346\}$ and $Z\{376\}$. It is in this zone that the form approximating to {356} and shown in figure 17 lies.

(3) Zone (001) : (110). The zone of unit pyramids is usually striated, there being thus two directions of striæ on $s\{112\}$, both of which are often well developed. A number of forms occur in this zone as line faces, $A\{114\}$, $B\{113\}$, $D\{223\}$, $\delta\{551\}$ and often $x\{331\}$, and less commonly $i\{221\}$, the faces of this last form usually being broader than line faces. The horizontal striæ only extend to the prisms, these last not showing any striation at all.



GNOMONIC PROJECTION OF MONTROYDITE FORMS.

(4) Zone (211) : (111) : (011). In this zone the striæ are not very prominently developed, usually showing best on {211} and {122}. The faces of {122} are often strongly striated in two directions, resulting in a rhombic grating effect. {111} also, at times, shows the two directions of striations on the same face. The other forms in this striated zone are {411}, {311}, {344}, {133} with {100} and {011}, these last, however, not showing the striations.

(5) Zone (001) : (100). The orthodome zone is striated, but the only large form in it {101} is not striated parallel to the dome intersections but normal thereto, namely in the zone (101) : (010). There is therefore a break in the orthodome striæ, the faces between (101) and (001) and between (101) and (100) being striated parallel to the intersections. The faces between (101) and (001), namely, E(103), g(102), M(203) are much more striated (especially g) than the remaining domes below (101), namely, n(302), q(201), and u(301).

(6) Zone (101) : (010). This is the last zone in which distinct striations were seen, and these were highly developed only in the one form {101}, the faces of which are very commonly strongly striated. Other forms in this zone are the line faces Δ\{313\}, π\{323\}, S\{232\} and the unit pyramid o\{111\}.

The six directions of striations here described are shown on the crystal illustrated in figure 8, which shows the forms a\{100\}, b\{010\}, m\{110\}, v\{012\}, q\{102\}, d\{101\}, u\{301\}, ρ\{7.3.13\}, s\{112\}, o\{111\}, i\{221\}, t\{122\}, e\{132\}, r\{211\}.

The form system of montroydite is shown in gnomonic projection in Plate IV, which well shows the distribution of the faces in zones, and also shows the symmetrical development of the mineral. The absence of the base is a rather unusual feature.

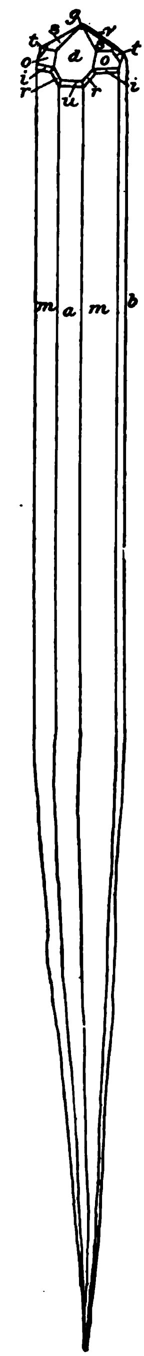


FIGURE 9.—Montroydite crystal: b\{010\}, a\{100\}, m\{110\}, v\{012\}, q\{102\}, d\{101\}, u\{301\} s\{112\}, o\{111\}, i\{221\}, t\{122\}, r\{211\}.

HABIT.

In habit montroydite varies between two extremes, long prismatic (fig. 9), the crystals not infrequently nearly 20 millimeters long and not more than 1 millimeter thick, to nearly equidiametral (fig. 20), averaging from 1 to 2 millimeters thick. All gradations can be found between these two extremes. As the crystals become longer in the direction of the vertical axis they decrease in thickness, so that the long prismatic ones are thinner than the short equidiametral ones.

Some of the long prismatic crystals bulge out at a certain point so that they are several times the usual thickness, decreasing to the normal thickness again a little farther along. Many of these long crystals are terminated at one end only, the other tapering down almost to a point (fig. 9). They are generally attached by the terminated end, the pointed end sticking out from the matrix. They are also often attached on the side, or a number of crystals are grouped irregularly together, many having both ends developed. Most, if not all, of the short equidiametral crystals are, however, doubly terminated, and these as well as the short prismatic ones (many of which are also doubly terminated) show that the mineral is holohedral in its crystal-

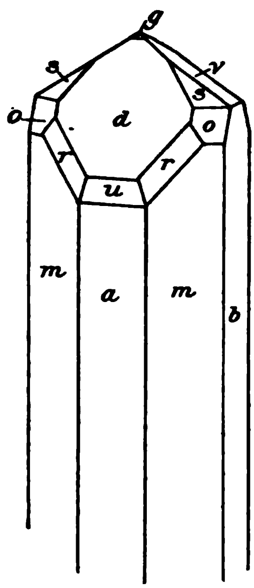


FIGURE 10.—Montroydite crystal 14: $b\{010\}$, $a\{100\}$, $m\{110\}$, $v\{012\}$, $g\{102\}$, $d\{101\}$, $u\{301\}$, $s\{112\}$, $o\{111\}$, $r\{211\}$.

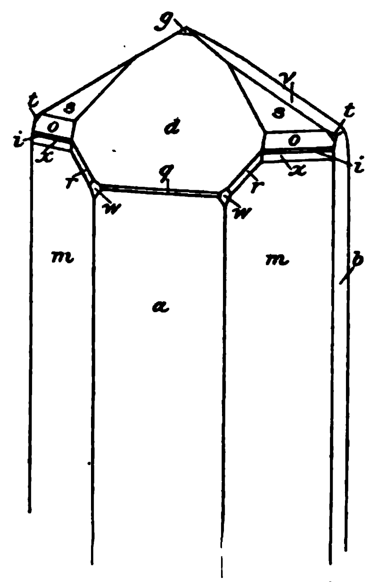


FIGURE 11.—Montroydite crystal 5: $i\{221\}$, $x\{331\}$, $r\{211\}$, $w\{311\}$, $t\{122\}$.

lographical development. Parallel intergrowths of a number of the equidiametral crystals are not uncommon and scepter intergrowths (one equidiametral crystal fastened in a parallel position to a long prismatic one) are also found (fig. 21).

A number of curiously distorted crystals also occur, their distortion being the result of unequal development of the different faces of the same forms. They have mostly a tabular habit, being flattened parallel to one face (fig. 22).

The crystals may then conveniently be grouped into three habits, as follows:

(*a*) Long prismatic, about 1 by 20 millimeters.

(*b*) Small equidimensional, about 2 by 2 millimeters.

(*c*) Flattened distorted crystals, rather thin and several millimeters across.

In the following description of the crystals they will be described in the order of their habit, commencing with the long prismatic

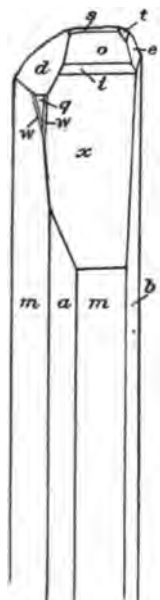


FIGURE 12.—Montroydite crystal 7: $q\{201\}$, $x\{331\}$, $w\{311\}$.

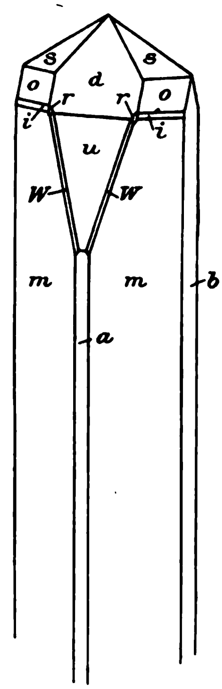


FIGURE 13.—Montroydite crystal 18: $u\{301\}$, $W\{411\}$.

crystals and gradually approaching the smaller equidimensional ones. Several characteristics of the crystal development go hand in hand with this change in habit, as some forms have large faces on the

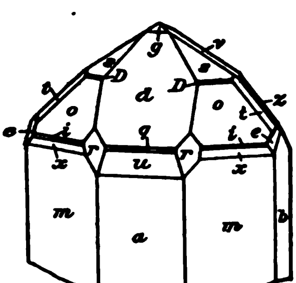


FIGURE 14.—Montroydite crystal 12: $q\{201\}$, $z\{011\}$, $D\{223\}$, $t\{122\}$, $e\{132\}$, $r\{211\}$.

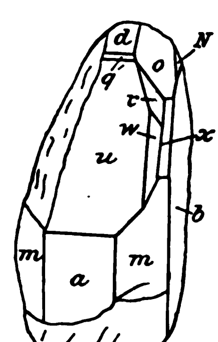


FIGURE 15.—Montroydite crystal 21: $q\{201\}$, $x\{331\}$, $w\{311\}$, $N\{263\}$.

one habit and are poorly represented or else entirely absent on the other. In passing from the first to the second habit, the orthopinacoid

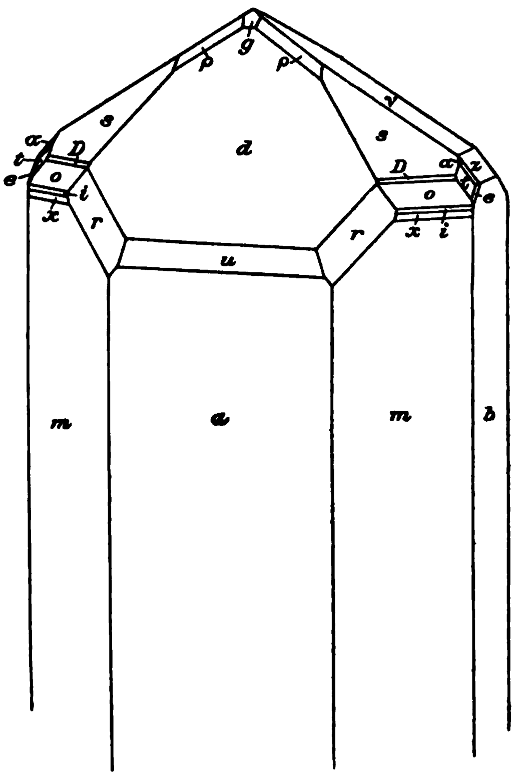


FIGURE 16.—Montroydite crystal 8: *z*{011}, *D*{223}, *α*{133}, *ι*{122}, *e*{132}, *ρ*{7.3.13}.

gradually changes from a vertical line face to a large face of the same diameter in the two directions, and finally to a horizontal line face.

DESCRIPTION OF CRYSTALS.

The long prismatic habit is shown by the majority of all the crystals we have seen, and is shown in figure 9, which does not represent any particular crystal measured, but gives their general appearance.

Except as otherwise stated, the illustrations of montroydite crystals are drawn in ideal development, as the crystals are usually fairly symmetrical, and such drawings show the symmetry better than a true drawing, where the deviation from ideal symmetry is but slight.

Crystal 14 (fig. 10) shows a development of faces not uncommon on these long crystals. All three forms in the prism zone *abm*, are well developed, being nearly equal in size, and they necessarily determine the habit. The dome $d\{101\}$ is the dominant terminal form, while $v\{012\}$, $s\{112\}$, $o\{111\}$, $r\{211\}$, and $u\{301\}$ are present as small faces. The minute dome $g\{102\}$ and the large faces of $r\{211\}$ are characteristic of these long prismatic crystals.

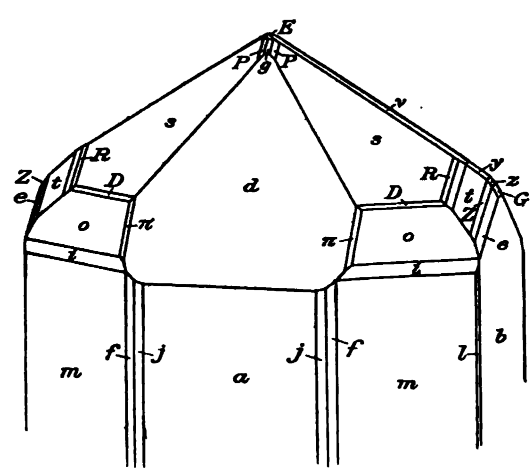


FIGURE 17.—Montroydite crystal 6: *l*{1.10.0}, *f*{320}, *j*{410}, *E*{103}, *P*{326}, *R*{346}, —{356}, *Z*{376}, *π*{323}, *y*{023}, *z*{011}, *G*{032}, *D*{223}.

Crystal 5 (fig. 11) shows a somewhat richer combination, though of the same general type as the preceding. The four pyramids, *s*{112}, *o*{111}, *i*{221}, and *x*{331}, commonly occur together, being usually of the relative sizes shown in figure 11. Small faces of *t*{122} are present, and *e*{132}, though not shown in this figure, often occurs with *t*{122}, these two being the only forms present in this zone between *s*{112} and *b*{010}, though on the equidimensional crystals this zone is much richer in forms.

Crystal 7 (fig. 12) shows an actual drawing of the combination as seen on the crystal. The termination is incomplete, but the very large development of *x*{331} gives it an unusual appearance. Moses noted the large size of the *x* faces on the crystal he measured, though this is a rather unusual feature for montroydite. The form *e*{132} is here shown for the first time.

On crystal 18 (fig. 13) the *a* faces are much narrower than either *b* or *m*, and approach the character of line faces. The form *u*{301} equals that of *d*{101} in its development, and this crystal shows the two faces of *W*{411}, as line faces between *u* and *m*. This form was not noticed on any other crystal.

Crystal 12 (fig. 14) shows a richer combination, with line faces of *D*{223}. Two faces were present, and though the measurements agree more closely with {335}, a form not elsewhere observed, they are referred to {223}.

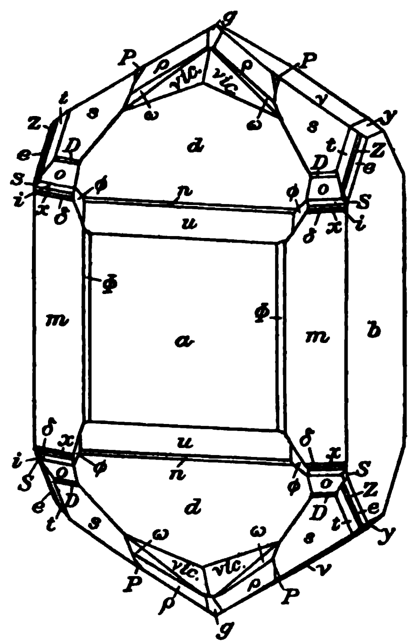


FIGURE 18.—Montroydite crystal 22: Φ{510}, g{023}, n{302}, D{223}, δ{551}, ϕ{632}, S{232}, Z{376}, ρ{7.3.13}, ω{10.1.12}, vic. {44.1.48}, P{326}.

	°	′
Meas. ρ(1)	54	10
Meas. ρ(2)	53	42
Calc. ρ{335}	53	12
Calc. ρ{223}	56	03

A long narrow face of *z*{011} is present, and *t*{122}, between it and *o*{111}, is also long and narrow.

Crystal 21 (fig. 15) is incomplete, and, like crystal 18 (fig. 13), shows a large development of *u*{301}. Many other forms, not shown in figure 15, are present as minute faces. The figure shows a small face of *N*{263}, a form also present on crystal 17. On crystal 21 the form is accompanied by a vicinal form, measurement of which gave values very close to those for {263}.

Measurements of N {263} and vicinal form, montroydite.

	ϕ		ρ	
	°	′	°	′
Calc. {263}	27	36	69	42
Meas.	27	47	69	57
Vicinal form	27	47	68	06

The form γ{542}, present once on this crystal, forms a line face between {211} and {331}. A narrow line face, in zone {112}, {010},

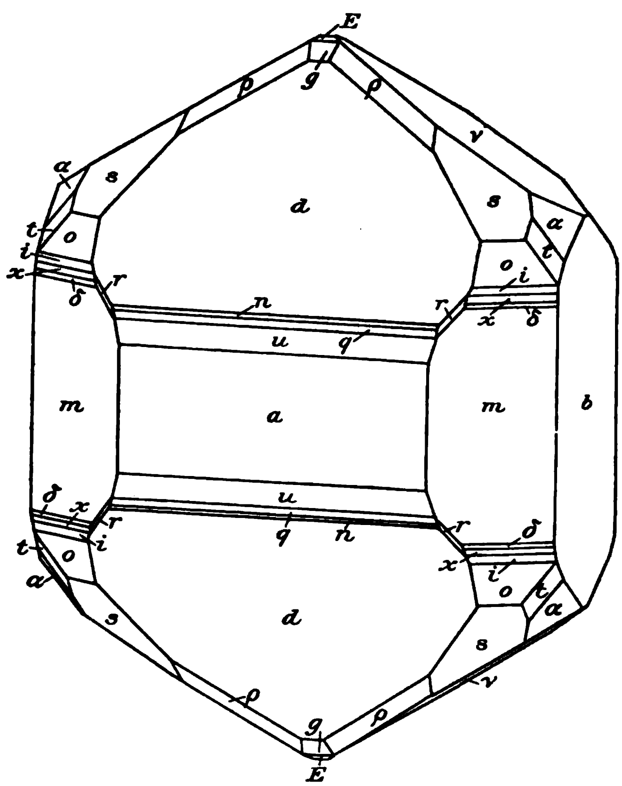


FIGURE 19.—Montroydite crystal 9: E{103}, n{302}, q{201}, δ{551}, ρ{7.3.13}, α{133}.

approximating to {356}, is present, but the measurement varied too widely from the calculated value for its reference to that form. A similar narrow face, near {356}, occurs on crystal 6 and is shown in figure 17, though the measurement here was also at variance.

Measurements of form near {356}, montroydite.

	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
Calculated			**43 16**	**58 58**
Measured:				
Crystal 6	Poor	Small	40 52	53 27
Crystal 21	Poor	Line face	44 57	56 02

Crystal 8 (fig. 16) shows in addition to the forms already shown small faces of $\rho\{7.3.13\}$, this form being usually absent on these long prismatic crystals, though very characteristic on the equidimensional ones. Small faces of $\alpha\{133\}$ and $D\{223\}$ are also shown. Two minute line faces of $A\{114\}$ are present, though not shown on the figure.

Crystal 6 (fig. 17) shows the chief forms of this small but very rich crystal. In habit it occupies an intermediate position, being short prismatic and already showing the characteristics of the equidimensional crystals. The number of brachydomes present is unusual, including, besides $v\{012\}$, the forms $y\{023\}$, $z\{011\}$, and $G\{032\}$. The prism zone is also rich in forms, a, b, m, $l\{1.10.0\}$, $f\{320\}$, and $j\{410\}$ being shown in figure 17, while in addition faces of $h\{120\}$, $\Phi\{510\}$, and $C\{230\}$ are present. Besides $d\{101\}$ and $g\{102\}$, there are two small line faces of $E\{103\}$. The zone $s\{112\}$, $b\{010\}$, is rich in faces, $P\{326\}$, $R\{346\}$, —$\{356\}$, $t\{122\}$, $Z\{376\}$, and $e\{132\}$ being present, besides g, s, and b. The form $\pi\{323\}$, between $d\{101\}$ and $o\{111\}$, is present but once, and only on this crystal.

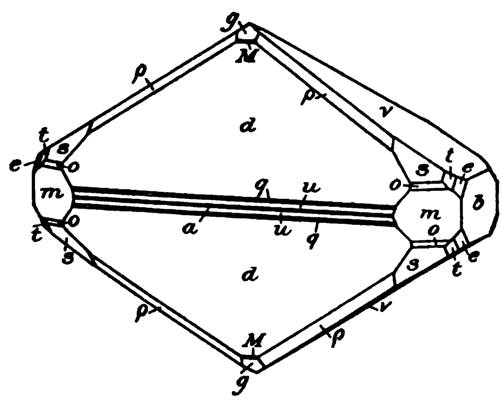


FIGURE 20.—Montroydite crystal 10: $M\{203\}$, $g\{201\}$, $\rho\{7.3.13\}$.

Crystal 22 (fig. 18) is short prismatic, nearly equidimensional, with a rich combination of forms. The form $\rho\{7.3.13\}$ is well developed, the zone $s\{112\}$, $b\{010\}$, is rich in forms, $r\{211\}$ is absent, and in addition the form $\omega\{10.1.12\}$ and the vicinal form $\{44.1.48\}$ are well developed. Two faces of $\Phi\{510\}$ are present, besides a, b, m in the prism zone. The pyramid zone, cm, shows $s\{112\}$, $D\{223\}$, $o\{111\}$, $i\{221\}$, $x\{331\}$, $\delta\{551\}$, and $B\{113\}$, the latter not shown in the figure. Small faces of the rare pyramids $S\{232\}$ and $\phi\{632\}$ are also

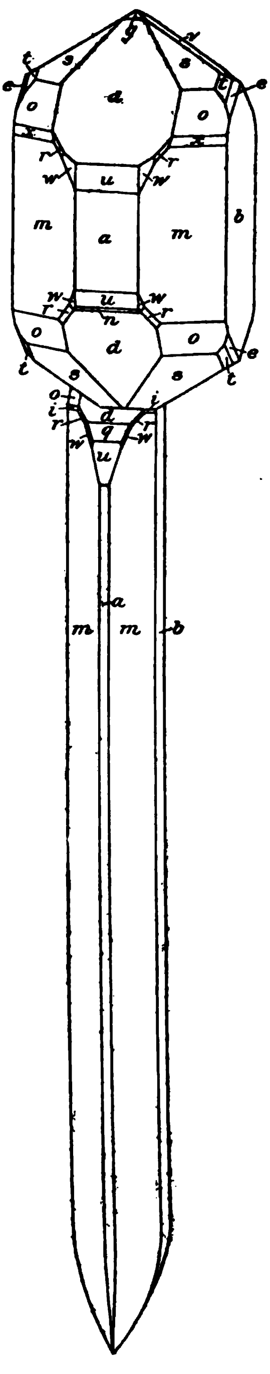


FIGURE 21.—Montroydite, scepter crystal (No. 24): $q\{201\}$, $n\{302\}$, $w\{311\}$.

shown in the figure, S occurring only on this crystal, while ϕ was observed on one other. The large faces of $\{44.1.48\}$ are rather unusual, for while vicinal forms are not rare they elsewhere occur as very narrow or line faces.

Crystal 9 (fig. 19) shows the second habit well—the equidimensional one. Another feature of crystals of this habit is well brought out in figure 19, namely, the number of forms in the orthodome zone, there being shown $E\{103\}$, $g\{102\}$, $d\{101\}$, $n\{302\}$, $q\{201\}$, and $u\{301\}$, besides $a\{100\}$. Two small faces of $r\{211\}$ are present, this form being rather unusual for crystals of this habit, and the single face of $\alpha\{133\}$ is much larger than usual.

Crystal 10 (fig. 20) shows the extreme development of the equidimensional habit, the crystal being somewhat longer in the direction of the b axis than in the vertical direction. In crystals of this type the a face is often the merest line. The development of the orthodome zone, mentioned in the case of the previous crystals, is here again well shown. The lower end of the clinodome zone is very much striated, making it impossible to determine any forms that may be present here. The long narrow faces of $\rho\{7.3.13\}$, striated and grading into $s\{112\}$, are very characteristic.

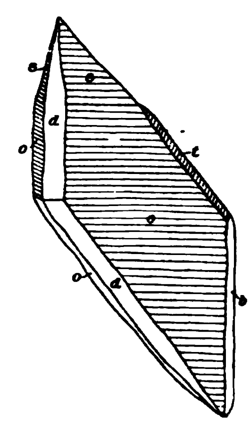


FIGURE 22.—Montroydite, distorted crystal (No. 23): $d\{101\}$, $s\{112\}$, $o\{111\}$, $t\{122\}$.

Crystal 24 (fig. 21) shows a scepter crystal, one of the second habit being perched in strictly parallel position on a long one of the first habit. Several such instances were noted, as well as others where two or more nearly equidimensional crystals were joined together in parallel position. In this latter arrangement, one crystal was always slightly

more prismatic than the other, no instance being observed where the two crystals superimposed in parallel position had exactly the same habit.

Crystal 23 (fig. 22) shows about the appearance of the peculiar distorted crystals of habit 3. They are so rounded and striated that their correct orientation is very difficult to determine, but it is believed that figure 22 shows the proper position of this crystal.

TERLINGUAITE.

FORMS.

Terlinguaite occurs in three forms, as distinct crystals, as a crystalline crust, and as a yellow powder.

1. As distinct crystals terlinguaite occurs on many of the specimens, often resting on or growing out of a crystalline mass (2), though often also resting directly on calcite. The crystals are usually several millimeters long, the largest one measuring 16 by 4 by 4 millimeters, and some of the imperfect crystals showing faces over a centimeter broad. The individual crystals show a number of habits, which are described on pages 126–132, and illustrated in figures 23 to 31. They may be grouped under the three general headings given below:

(*a*) Equidimensional, small and very rich in faces.

(*b*) Elongated in one direction (usually the *b* axis), and then often striated.

(*c*) Tabular to some form (mostly $a\{100\}$).

2. As a crystalline crust terlinguaite is found usually intimately associated with montroydite and forming a greenish mass which often contains a considerable quantity of well-crystallized material.

3. The mineral is frequently found as a yellow powder which changes to a gray or greenish color after exposure to light. Of the powdery forms in which these minerals occur it is, perhaps, the most abundant, coloring not only the pink earthy gangue but also the layer of coarse calcite.

PHYSICAL PROPERTIES.

COHESION, ETC.

The cleavage of terlinguaite is perfect and is parallel to the rear unit orthodome $u\{\bar{1}01\}$ in the orientation chosen by the writer, or to the dome $\{\bar{1}03\}$ in the orientation of Moses. No indication of any other cleavage was seen, and not only is this perfect cleavage easy to obtain but almost all (if not all) of the faces of $\{\bar{1}01\}$ present on the crystals measured are cleavage faces. It was not found possible to so orient the crystals as to make the cleavage

parallel to either the base or the orthopinacoid and at the same time to preserve the simplicity of the indices of the 134 forms. For a discussion of this point see part of the section on crystallography (p. 132).

The mineral is brittle, breaking with an uneven fracture, and is neither elastic nor plastic. Though described by Moses as brittle or subsectile, no indication of sectility was observed, the crystals invariably cutting to a powder. Terlinguaite thus shows marked differences in these properties from montroydite.

The hardness was found to be between 2 and 3, as given by Moses.

DENSITY.

The density was not determined by us, as so much of the mineral contains included mercury. Two determinations by Moses gave 8.728 and 8.723.[a]

LUSTER, COLOR, ETC.

The luster is adamantine and sometimes very brilliant. Rarely there is a faint indication of a greasy luster.

Much confusion seems to exist as to the original color of terlinguatie before it has been exposed to light. Moses writes of it as "sulphur-yellow with a slightly greenish tinge, very slowly darkening on exposure to an olive green," and that "the most convenient distinctions [from eglestonite] are the yellow color and the very slow change of color to olive green as compared to the brownish color and rapid change to black with eglestonite." But H. W. Turner (p. 259 of the paper by Moses) is quoted in a statement implying that the original color is yellow-green, and Mr. Hartley, in reply to our inquiry, wrote that the terlinguaite crystals were green before they were touched by sunlight, but that most of the terlinguaite occurs as a yellow powder changing to green. The crystals which were measured over two years ago and have lain since that time in the dark are decidedly more sulphur-yellow than green, but unfortunately, not knowing of this apparent confusion in regard to their color, the authors then took no note of their exact shade. It may be possible that terlinguaite, if sulphur-yellow originally and turned green by exposure to light, returns to its yellow color after considerable lapse of time if kept in the dark. At any rate, we have specimens that show a greenish or dark yellowish-green color as well as the sulphur-yellow, and the color of the mineral must be so described as to include both the sulphur-yellow and the greenish or light olive-green colors. Sometimes brown crystals are seen, and occasionally the green and brown

[a] This inclosed mercury, so characteristic of all these minerals except kleinite, renders the few values given by Moses more or less doubtful.

colors appear in the same crystal. When brown they are difficult to distinguish at sight from eglestonite in one of its transitional color stages. Some of our earthy specimens that were yellow at first turned greenish on exposure, and presumably contained terlinguaite. Beautiful spots of emerald-green reflected light appear when the crystals are examined with a lens as they occur on the specimen. If at times originally yellow the mineral is not in that state always distinguishable from kleinite, and perhaps not from eglestonite or even from the orange-red form of montroydite. The color of terlinguaite may then be defined as sulphur-yellow, olive-green of varying shades, and brown, of which the sulphur-yellow probably changes to the olive-green. In transmitted light the colors are olive-green, becoming in thin sections very pale. There is a slight pleochroism, in one direction of a greenish, and normal thereto of a yellowish, shade. The streak is yellow, turning greenish-gray on exposure. The crystals, if bounded by parallel faces, are transparent, though the large number of faces usually present makes the crystals translucent.

OPTICAL PROPERTIES.

The extinction was measured on the clinopinacoid, the angle being determined by Klein's Universal Drehapparat fastened to a microscope, with the mineral immersed in monobromnaphthalene. The crystal fragment was so turned that the clinopinacoid was parallel to the stage of the microscope. Extinction measured with regard to direction of edge (010):($\bar{1}$01) is, to left, 39°, to right, 51°. Therefore one extinction direction (on (010)) is inclined 7° to the rear from the vertical axis, while the other direction emerges nearly normal to the *a* face (100) or exactly 83° down in front of the vertical axis. This is for daylight. The faces on this section were determined by the following measurements on the two-circle goniometer:

Cleavage.	Measurements.	Calculation.
	° ′	° ′
(100): (10$\bar{1}$)	44 07	44 04
(010): (10$\bar{1}$)	90 00	90 00

On another crystal fragment a section was ground down approximately parallel to *a*(100). This showed the emergence of a bisectrix, and the trace of the axial plane was parallel to the striations on the *a*(100) face. As these striations are parallel to the *b* axis, the orientation of the axial plane for terlinguaite is as follows: Axial

plane nearly parallel with a plane containing the *a* and *b* axis but inclined 7° up in front. The axial angle in air is very large. The above-stated determinations could not be verified on other crystals, so that some hesitancy is felt about advancing them as perfectly correct. Should some future determinations be at variance with them this doubt should be borne in mind. The indices of refraction could not be measured, though approximate determinations with the microscope gave values considerably greater than 2.

CHEMISTRY.

PYROGNOSTIC BEHAVIOR.

The effect of heating terlinguaite crystals in a closed tube differs somewhat, according as this is done slowly or quickly. When quickly done there is violent decrepitation, continuing until the mineral has volatilized, the mineral turning red-brown or almost vermilion in color, and much of the resulting powder being projected up onto the sublimate of calomel and mercury above the assay. Eventually there is complete volatilization of the remaining mercuric oxide, but if the heating is stopped before the end, the oxide on cooling is orange-yellow. When the heating is very slowly done, decrepitation is hardly to be noticed. With the first burst of sublimation there appears a little mercury, but then only calomel so long as there is any chlorine left in the residue. Sometimes at the last, when the flame is removed, brilliant short red needles of mercuric oxide form on the warm glass by recombination of some of the mercury vapor and oxygen.

If the heating is done in vacuo the color changes of the crystals as the heat increases are most marked, these being, after the first appearance of a sublimate, red, black (without loss of luster), red-brown, orange-brown (orange, cold), and dull. Before the crystals become completely orange-brown some faces are olive-greenish. When the crystals are orange-brown the only visible sublimate is calomel, and no trace of oxygen has been evolved. The residue now seems to be mercuric oxide. When it decomposes partial recombination of its constituents occurs, to judge from the deposition on the warm glass near by of a slight orange-brown sublimate.

BEHAVIOR TOWARD REAGENTS.

Hydrogen sulphide blackens a crystal of terlinguaite at once, ammonia only after some time. Both tests serve to distinguish the mineral from kleinite and the second from eglestonite, which is at once blackened by ammonia. Hydrochloric and nitric acids readily decompose the mineral, with separation of calomel. The hydrochloric acid filtrate yields much divalent mercury. Cold dilute

acetic acid slowly decomposes the mineral in powder form, also with separation of calomel, and in the filtrate hydrochloric acid produces no further precipitate, or but a very faint one, showing the absence in the original substance of univalent mercury in combination with oxygen. Hereby is afforded a decisive chemical test to distinguish terlinguaite from eglestonite, which, under similar conditions, yields a further heavy precipitate of calomel with hydrochloric acid. This test, coupled with the first showing of calomel when the mineral is decomposed, shows that terlinguaite is a mercuric-mercurous compound.

QUANTITATIVE COMPOSITION.

The empirical formula of Moses (Hg_2ClO) was confirmed by the following analyses, in which the supposed oxygen was measured directly and found to be wholly absorbed by phosphorus. The crystals, while very fine, are seldom procurable entirely free from attached or imbedded globules of mercury.

Analyses of terlinguaite.

	1.	2.	3.
Hg	88.92	86.73	[a]85.65
Cl			7.58
O			3.63
Nonvolatile	None.	1.79	3.14
			100.00

Analyses of terlinguaite calculated to gangue-free basis.

	1.	2.	3.	Ratio of 3.	Theory (Hg_2ClO).
Hg	88.92	88.31	[b]88.61	2.00	88.65
Cl			7.83	1.00	7.85
O			3.75	1.06	3.50
			100.19		100.00

[a] Difference. [b] Mean of 1 and 2.

1. Weight, 0.2502 gram. Selected crystals free from nonvolatile matter, but with a little native mercury imbedded. Mercury weighed as sulphide after solution of the mineral in hydrochloric acid aided by a little bromine, removal of the excess of bromine by just enough sulphur dioxide, and precipitation by hydrogen sulphide.

2. Weight, 0.2072 gram. Crystals free from native mercury. Dissolved in sodium sulphide, wherein about 22 per cent of mercury separated in the free state with gangue. These were easy to separate. The rest of the mercury was obtained from the alkaline solution by electrolysis, as described under kleinite (p. 37).

3. Weight, 0.1052 gram. Crystals containing a little montroydite and free mercury. Volatilized in a tube attached to pump, using gold leaf to retain mercury vapor. The chlorine was extracted from the sublimate by caustic alkali and determined as usual. The gas collected showed no contraction when treated with caustic alkali and was wholly absorbed by phosphorus.

The high oxygen found in analysis 3 is due probably more to error in measuring so small a volume as 2.67 cubic centimeters (0° and 760 mm.) than to the little montroydite that was present.

The only artificial mercuric-mercurous oxychloride hitherto prepared[a] has the empirical formula of terlinguaite. It was made by heating with water at 180° equivalent weights of mercuric oxide and calomel, but its system of crystallization was not ascertained.

CRYSTALLOGRAPHY.

GENERAL DESCRIPTION.

The fundamentals of the crystallography of terlinguaite were determined by Moses and but slight changes have been made in them. The orientation chosen by him has been retained, as it gives the simplest indices and shows the geometric relations of the various forms very well. The only disadvantage is that the perfect cleavage of the mineral is parallel to the unit negative dome $\{\bar{1}01\}$, but, as described in detail further on, it was not found possible to so orient the crystals as to make the cleavage a pinacoidal form and at the same time retain the simplicity of the forms. That terlinguaite possesses a rich form system was already shown by Moses's measurements of but four minute crystals, showing the presence of 32 forms. This number the writer has been able to extend by about a hundred forms, for the greater part simple in their indices and lying in well-developed zones. It was found that the indices of Moses could be much simplified by multiplying the first (in the Millerian form) by 3; thus $h.\ k.\ l$ becomes $3h.\ k.\ l$. Both of these are given under the form description, so that they may be better compared with the results of Moses, and also to illustrate how much simpler the forms are in their new indices. For reference, the indices in the form given by Moses are referred to as M_1, those in the new form as M_2. In the later tables, only the form finally adopted, namely M_2, is given. A few forms of Moses, with very high and vicinal indices, have been much simplified, and, in one case, two of his forms have been united into one. As the best orientation could not be determined until all the crystals had been measured and determined, the new elements were calculated on the basis of the former indices, namely, M_1, but the discussion of the forms is carried out in the orientation finally chosen and put forward in this paper as the most suitable one for terlinguaite, namely, M_2. Therefore, $h.\ k.\ l\ (M_1) = 3h.\ k.\ l\ (M_2)$.

Though not particularly large, the crystals are exceedingly rich in forms, many of the faces being very minute. It would have been utterly impossible to completely determine the various forms without the two-circle goniometer.

[a] Fischer, T., and Von Wartenberg, H., Chem. Zeitung, vol. 29, 1905, p. 308.

The following table shows the number of determined forms and faces on the twelve crystals measured, all doubtful and vicinal ones being excluded:

Number of forms and faces on twelve terlinguaite crystals.

Crystal No.—	Forms.	Faces.	Crystal No.—	Forms.	Faces.
1	54	86	7	52	83
2	32	48	8	51	58
3	41	59	9	67	80
4	41	55	10	45	53
5	38	43	11	64	96
6	87	174	12	39	48

The sizes of the twelve (often incomplete) crystals measured are shown below:

Dimensions of terlinguaite crystals.

Crystal No.—	Dimensions (millimeters).
1	2½ by 1½ by 1½.
2	1 by 1 by ½.
3	2¼ by 1½ by ½.
4	2¼ by 1 by ½.
5	2 by ¾ by ½.
6	15 by 1¾ by 1¾.
7	2¼ by 1½ by ¾.
8	3¼ by 2 by 1½.
9	2 by 1½ by 1.
10	1½ by 1½ by ¾.
11	2 by 1½ by 1¼.
12	1½ by 1½ by ½.

CALCULATION OF ELEMENTS.

On account of the large number of faces present which give good reflections, a new set of values were calculated for the crystallographical elements. The two-circle goniometer is beautifully adapted for the determination of the crystallographical elements of a mineral, as each reading may or may not be directly used, according as to whether or not it gave a good reflection. As there are so many faces and forms on the terlinguaite crystals measured, a fairly exact value may be obtained.

For the determination of the angle β, there are three means at hand, namely (1) direct measurement, or, what is practically the same thing, taking the complement of the ρ measurement on the basal pinacoid; (2) the ϕ reading of all faces in the zone (001) : (010), if the crystal is set up with the clinopinacoid polar; and (3) obtaining

the cot β ($=e'$) from measurements of the clinodomes, since sin ϕ tan $\rho=x$ and $x'=e'=\cot\beta$ for clinodomes.

Using only the measurements of such faces as gave good signals, the following results were obtained:

The angle β measured directly on terlinguaite crystals.

Crystal No.—	Reflection.	Angle.	Crystal No.—	Reflection.	Angle.
		° ′			° ′
1	Excellent.....	74 23	6	Excellent.....	74 23
1	Good..........	22	6	Fair............	21
2	Good..........	22	6	Fair............	25
2	Fair............	22	9	Fair............	23
3	Good..........	24	10	Excellent.....	23
4	Excellent.....	25	11	Excellent.....	23
4	Good..........	23			
6	Excellent.....	23	Average .	....	74 22.8

From this average is obtained $e'=0.27957$.

In the crystals adjusted by using orthodomes as the prisms and setting the clinopinacoid as pole, the ϕ angle for any form in the zone (001) : (010) is the same as the complement of β. The following are the ϕ angles for such clinodomes as are present on those parts of crystal 6 that were set up in this position.

Measurements of ϕ angle on clinodomes of terlinguaite crystal No. 6.

	° ′
25 measurements..........	15 37
3 measurements..........	32
7 measurements..........	41
4 measurements..........	38
1 measurement..........	43
2 measurements..........	35
2 measurements..........	36
2 measurements..........	42
2 measurements..........	34
1 measurement..........	33
Average..........	15 37.3

Or, if $\phi=15°\ 37.3'$, $\beta=74°\ 22.7'$, and hence is obtained $e'=0.27962$.

The values for e' obtained from the direct measurements of the clinodomes, the crystal being adjusted polar, are as follows:

Values of e' obtained from measurements of clinodomes, terlinguaite crystals.

Number of measurements.	Value.	Number of measurements.	Value.
5	0.2793	1	0.2794
10	.2790	1	.2807
1	.2805	1	.2810
1	.2798	2	.2796
1	.2789	2	.2799
6	.2801	7	.2802
1	.2776	4	.2787
1	.2774	3	.2813
3	.2795	5	.2797
2	.2803		
1	.2806	58	Av. .27965

The values obtained for e' are then:

From β measured directly (14 measurements).................. 0.27957
From ϕ angle of clinodomes ($90°-\beta$) (49 measurements)....... .27962
From clinodomes (58 measurements)............................ .27965

Average (121 measurements).................................. .2796

Hence $e'=0.2796$; $\beta=74° 22' 40''+$, or $74° 23'$.

For the determination of p'_0 or q'_0, the average measurements were used for each of the forms of which at least three faces gave concordant measurements, and only such measurements were used as agreed closely with the general average. From the pyramids and clinodomes, the values for q'_0 were obtained; from the pyramids and orthodomes and prisms (using the value of q'_0 obtained and the equation $p'_0=\frac{k}{h} q'_0 \tan \phi$), the values for p'_0 were obtained.

The values are as follows:

Values of p'_0 and q'_0, terlinguaite crystals.

p'_0.		q'_0.	
Number of measurements.	Value.	Number of measurements.	Value.
10	3.9379	10	2.0237
6	3.9360	6	2.0231
32	3.9366	25	2.0228
24	3.9354	15	2.0246
5	3.9318	5	2.0241
21	3.9348	21	2.0257
8	3.9294	21	2.0220
11	3.9339	11	2.0234
9	3.9828	4	2.0139
10	3.9762	3	2.0115
12	3.9402	9	2.0182
13	3.9335	12	2.0215
8	3.9592	8	2.0374
20	3.9303	20	2.0297
14	3.9355	14	2.0206
22	3.9428	31	2.0264
13	3.9521	13	2.0296
15	3.9390	23	2.0250
18	3.9336	16	2.0259
7	3.9591	19	2.0252
9	3.9144	12	2.0175
12	3.9312	14	2.0260
7	3.9353	11	2.0230
18	3.9309	5	2.0207
13	3.9344	17	2.0265
12	3.9306	10	2.0245
12	3.9357	5	2.0298
14	3.9497	8	2.0256
11	3.9162	10	2.0310
5	3.9242	8	2.0307
17	3.9357	11	2.0370
10	3.9390	11	2.0216
9	3.9312	14	2.0265
8	3.9672	14	2.0232
10	3.9411	4	2.0315
6	3.9464	19	2.0223
8	3.9510		
11	3.9270	459	Av. 2.0245
6	3.9375		
7	3.9368		
8	3.9384		
4	3.9333		
7	3.9136		
19	3.9392		
19	3.9369		
540	Av. 3.9330		

The elements for terlinguaite then become:

$p'_0 = 3.9380$ $\qquad a = .5338$

$q'_0 = 2.0245$ $\qquad c = 2.0245$

$e' = .2796$ $\qquad \beta = 74° 23'$

The values obtained by Moses, based on a much smaller number of measurements, are very close to the above. His values are: $a:b:c = .5306:1:2.0335$, $\beta = 74° \ 16'$.

These constants are based on the orientation of Moses. Therefore, on changing the elements from the position M_1, we obtain the following as the correct orientation M_2:

$p'_0 = 1.3127$	$a = 1.6050$
$q'_0 = 2.0245$	$c = 2.0245$
$e' = .2796$	$\beta = 74° \ 23'$

FORMS AND ANGLES.

The complete list of 134 established forms is shown in the table below, which gives the two orientations M_1 and M_2, the letters for the forms and the average of the measured angles compared with the calculated values. All doubtful and vicinal forms are excluded. These latter are shown together on page 108. Forms marked with a star are new.

Forms and angles on terlinguaite crystals.

No.	Letter.	Symbol.		Measured.				Calculated.			
		M_1	M_2	ϕ		ρ		ϕ		ρ	
				°	′	°	′	°	′	°	′
1	*c*	001	001	90	00	15	37	90	00	15	37
2	*b*	010	010	0	00	90	00	0	00	90	00
3	*a*	100	100	90	00	90	00	90	00	90	00
4	**j*	160	120	17	58	90	00	17	58	90	00
5	*$\mathfrak{u}$	290	230	23	28	90	00	23	23	90	00
6	*m*	130	110	32	57	90	00	32	58	90	00
7	**B*	120	320	44	11	90	00	44	12	90	00
8	δ	230	210	52	21	90	00	52	22	90	00
9	*$\mathfrak{m}$	560	520	58	21	90	00	58	20	90	00
10	*$\mathfrak{d}$	890	830	60	10	90	00	59	58	90	00
11	*$\mathfrak{e}$	210	610	76	20	90	00	75	35	90	00
12	**D*	031	031	2	38	80	39	2	38	80	40
13	*d*	011	011	7	52	63	56	7	52	63	56
14	*$\mathfrak{f}$	045	045	9	46	58	51	9	48	58	41
15	*$\mathfrak{g}$	035	035	13	32	50	04	12	58	51	16
16	*$\mathfrak{h}$	012	012	15	24	46	34	15	26	46	24
17	*$\mathfrak{a}$	049	049	17	23	43	04	17	15	43	18
18	*$\mathfrak{b}$	025	025	19	33	39	53	19	03	40	35
19	*f*	013	013	22	31	36	10	22	30	36	09
20	*h*	015	015	34	36	26	12	34	37	26	12
21	*$\mathfrak{l}$	017	017	44	17	21	56	44	01	21	55
22	*$\mathfrak{n}$	1.0.15	105	90	00	28	28	90	00	28	28
23	*$\mathfrak{o}$	1.0.12	104	90	00	32	02	90	00	31	18
24	*$\mathfrak{p}$	109	103	90	00	35	24	90	00	35	39
25	*$\mathfrak{z}$	108	308	90	00	37	29	90	00	37	40
26	*t*	106	102	90	00	43	05	90	00	43	06
27	*$\mathfrak{r}$	209	203	90	00	49	03	90	00	49	07
28	*$\mathfrak{M}$	104	304	90	00	51	40	90	00	51	39
29	*y*	103	101	90	00	57	59	90	00	57	52
30	*$\mathfrak{s}$	409	403	90	00	63	50	90	00	63	46

Forms and angles on terlinguaite crystals—Continued.

No.	Letter.	Symbol.		Measured.				Calculated.			
		M_1	M_2	ϕ		ρ		ϕ		ρ	
				°	′	°	′	°	′	°	′
31	*F	509	503	90	00	67	47	90	00	67	56
32	w	101	301	90	00	76	17	90	00	76	40
33	*G	403	401	90	00	79	12	90	00	79	45
34	*η	301	901	90	00	85	19	90	00	85	16
35	*[illegible]	401	12. 0. 1	90	00	86	34	90	00	86	26
36	*M	$\bar{1}$. 0. 21	$\bar{1}$07	90	00	4	58	90	00	5	16
37	*L	$\bar{1}$. 0. 12	$\bar{1}$04	90	00	2	40	90	00	2	13
38	*[illegible]	$\bar{1}$09	$\bar{1}$03	90	00	8	47	90	00	8	59
39	n	$\bar{1}$06	$\bar{1}$02	90	00	20	35	90	00	20	39
40	*[illegible]	$\bar{1}$05	$\bar{3}$05	90	00	26	50	90	00	26	56
41	*N	$\bar{2}$09	$\bar{2}$03	90	00	30	45	90	00	30	47
42	*[illegible]	$\bar{1}$04	$\bar{3}$04	90	00	35	14	90	00	35	11
43	*R	$\bar{4}$. 0. 15	$\bar{4}$05	90	00	37	36	90	00	37	37
44	u	$\bar{1}$03	$\bar{1}$01	90	00	45	52	90	00	45	56
45	*Π	$\bar{2}$05	$\bar{6}$05	90	00	52	25	90	00	52	20
46	*P	$\bar{4}$09	$\bar{4}$03	90	00	55	46	90	00	55	47
47	*Q	$\bar{1}$02	$\bar{3}$02	90	00	59	21	90	00	59	23
48	*[illegible]	$\bar{5}$09	$\bar{5}$03	90	00	62	24	90	00	62	21
49	x	$\bar{2}$03	$\bar{2}$01	90	00	66	52	90	00	66	55
50	*[illegible]	$\bar{5}$06	$\bar{5}$02	90	00	71	19	90	00	71	35
51	z	$\bar{1}$01	$\bar{3}$01	90	00	74	41	90	00	74	43
52	*S	$\bar{4}$03	$\bar{4}$01	90	00	79	01	90	00	78	38
53	*θ	$\bar{5}$03	$\bar{5}$01	90	00	81	09	90	00	80	58
54	*[illegible]	$\bar{7}$03	$\bar{7}$01	90	00	83	54	90	00	83	36
55	*[illegible]	$\bar{4}$01	$\overline{12}$. 0. 1	90	00	86	32	90	00	86	18
56	*[illegible]	117	317	71	57	41	54	71	03	41	41
57	s	111	311	64	22	77	56	64	22	77	56
58	*U	$\bar{1}$. 1. 11	$\bar{3}$. 1. 11	23	32	11	16	23	05	11	19
59	*V	$\bar{1}$19	$\bar{3}$19	35	21	15	19	35	05	15	22
60	q	$\bar{1}$15	$\bar{3}$15	51	32	32	59	51	27	33	01
61	a	$\bar{1}$13	$\bar{3}$13	56	55	50	56	56	51	50	59
62	o	$\bar{1}$11	$\bar{3}$11	61	06	76	35	61	02	76	33
63	*[illegible]	1. 30. 30	1. 10. 10	11	30	64	10	11	28	64	10
64	*τ	1. 24. 24	188	12	24	64	12	12	25	64	15
65	*[illegible]	1. 18. 18	166	13	30	64	37	13	10	64	23
66	*[illegible]	1. 15. 15	155	14	55	64	32	15	00	64	30
67	*ζ	1. 12. 12	144	16	43	64	40	16	43	64	41
68	*[illegible]	199	133	19	31	65	01	19	30	65	02
69	*Z	166	122	24	48	65	51	24	49	65	51
70	v	155	355	.....	.....	.....	.....	27	48	66	24
71	*Y	299	233	29	40	66	46	29	42	66	47
72	*[illegible]	144	344	31	56	67	21	31	59	67	16
73	p	133	111	38	09	68	47	38	11	68	47
74	r	499	433	45	03	70	35	45	00	70	45
75	*χ	122	322	47	59	71	41	48	00	71	43
76	*[illegible]	599	533	50	35	72	30	50	38	72	36
77	i	233	211	55	07	74	13	55	08	74	14
78	*[illegible]	433	411	69	55	80	20	69	54	80	22
79	*σ	$\bar{1}$. 15. 15	$\bar{1}$55	0	29	63	34	0	29	63	43
80	*ϕ	$\bar{1}$. 12. 12	$\bar{1}$44	1	29	63	39	1	22	63	43

Forms and angles on terlinguaite crystals—Continued.

No.	Letter.	Symbol.		Measured.				Calculated.			
		M_1	M_2	ϕ		ρ		ϕ		ρ	
				°	′	°	′	°	′	°	′
81	*X	$\bar{1}99$	$\bar{1}33$	4	35	63	46	4	28	63	47
82	*𝔏	$\bar{2}.15.15$	$\bar{2}55$	7	15	64	03	6	55	63	53
83	*ψ	$\bar{1}66$	$\bar{1}22$	10	34	64	04	10	33	64	06
84	*ω	$\bar{1}55$	$\bar{3}55$	14	31	64	25	14	05	64	24
85	*Δ	$\bar{2}99$	$\bar{2}33$	16	23	64	37	16	23	64	39
86	*Γ	$\bar{1}44$	$\bar{5}44$	19	13	65	08	19	12	65	00
87	*[illegible]	$\bar{2}77$	$\bar{6}77$	21	45	65	27	22	40	65	30
88	e	$\bar{1}33$	$\bar{1}11$	26	55	66	17	27	02	66	15
89	l	$\bar{4}99$	$\bar{4}33$	36	01	68	11	36	00	68	13
90	*[illegible]	$\bar{1}22$	$\bar{3}22$	40	05	69	22	39	51	69	14
91	g	$\bar{2}33$	$\bar{2}11$	49	13	72	08	49	12	72	07
92	*[illegible]	$\bar{5}66$	$\bar{5}22$	56	08	74	40	55	57	74	32
93	r	$\bar{4}33$	$\bar{4}11$	67	52	79	29	67	50	79	27
94	*[illegible]	126	326	54	00	48	57	54	09	49	03
95	*[illegible]	128	328	56	31	43	33	56	45	42	43
96	k	134	334	....		....		39	47	63	09
97	$\varkappa$	136	112	42	40	53	59	42	45	54	02
98	*[illegible]	137	337	44	08	50	21	44	09	50	25
99	*O	139	113	46	42	44	34	46	44	44	33
100	λ	1.3.15	115	53	15	34	05	53	15	34	05
101	*s	1.4.14	3.4.14	43	56	39	12	44	07	38	52
102	*Σ	1.6.12	124	30	56	49	45	30	59	49	44
103	*𝔛	1.6.18	126	36	32	40	06	36	27	40	00
104	*[illegible]	1.6.24	128	41	18	33	59	41	14	33	56
105	*Λ	193	131	14	19	81	07	14	41	80	57
106	*W	232	632	55	01	78	52	54	15	79	07
107	*θ	236	212	57	38	61	54	57	32	62	04
108	*T	239	213	59	38	53	15	59	42	53	13
109	*[illegible]	2.3.15	215	62	01	42	07	63	17	42	00
110	*[illegible]	$\bar{1}24$	$\bar{3}24$	34	57	50	59	34	51	50	58
111	*Ξ	$\bar{1}34$	$\bar{5}34$	26	15	59	33	24	54	59	09
112	*ρ	$\bar{1}39$	$\bar{1}13$	13	15	34	49	13	11	34	44
113	*H	$\bar{1}.3.12$	$\bar{1}14$	5	21	26	00	5	29	26	57
114	β	$\bar{1}.3.15$	$\bar{1}15$	2	23	22	11	2	25	22	04
115	*ι	$\bar{1}.6.12$	$\bar{1}24$	2	40	45	26	2	45	45	23
116	*I	$\bar{1}93$	$\bar{1}31$	9	38	80	46	9	39	80	47
117	*J	$\bar{2}.1.15$	$\bar{6}.1.15$	61	55	15	46	61	12	15	39
118	*K	$\bar{2}31$	$\bar{6}31$	51	26	84	14	51	18	84	07
119	*μ	$\bar{2}32$	$\bar{6}32$	50	20	77	33	50	18	78	07
120	*𝔪	$\bar{2}35$	$\bar{6}35$	46	56	60	42	46	47	60	35
121	*Ω	$\bar{2}36$	$\bar{2}12$	45	44	55	21	45	35	55	20
122	*ξ	$\bar{2}39$	$\bar{2}13$	41	27	41	58	41	26	41	59
123	*𝔱	$\bar{2}.3.15$	$\bar{2}15$	31	11	25	21	31	14	25	20
124	*𝔫	$\bar{2}.3.18$	$\bar{2}16$	24	54	19	52	25	05	20	26
125	*A	$\bar{2}.3.21$	$\bar{2}17$	17	52	16	53	18	16	16	56
126	*C	$\bar{4}39$	$\bar{4}13$	65	22	58	17	65	21	58	17
127	*[illegible]	$\bar{4}.3.15$	$\bar{4}15$	62	26	41	06	62	17	41	03
128	*𝔄	$\bar{4}.3.33$	$\bar{4}.1.11$	47	21	15	07	47	03	15	07
129	*𝔈	$\bar{4}.9.15$	$\bar{4}35$	32	37	55	17	33	20	55	29
130	*E	$\bar{5}39$	$\bar{5}13$	70	29	63	41	70	31	63	45
131	*Υ	$\bar{5}.3.15$	$\bar{5}15$	68	30	47	57	68	36	47	59
132	*[illegible]	$\bar{5}.3.27$	$\bar{5}19$	63	39	26	35	63	21	26	38
133	*[illegible]	$\bar{5}.6.12$	$\bar{5}24$	53	19	59	31	53	22	59	29
134	*[illegible]	$\bar{8}.3.12$	$\bar{8}14$	77	42	67	30	77	48	67	20

As with montroydite, the forms of terlinguaite are divided into three classes, according to their prominence. In the first class are the common forms which are present on most of the crystals measured, and probably would have been found on all had the crystals been complete.

DESCRIPTION OF COMMON FORMS.

Moses described two domes, $m\{\bar{5}08\}$ and $x\{\bar{7}.0.10\}$, which have been combined into the simpler form $x\{\bar{2}03\}$. Neither $\{\bar{5}08\}$ nor $\{\bar{7}.0.10\}$ was found by the writer. Both these forms were described as large faces, and as the form system of terlinguaite shows that most of its forms have simple indices it seems improbable that "large faces" would have such complex symbols as were ascribed to m and x. These symbols become still more complex and also decidedly vicinal if they be changed from the orientation M_1 (as given above) to the correct one M_2, which results in simplifying the symbols of the different forms. The two forms then become $m\{\bar{15}.0.8\}$ and $x\{\bar{21}.0.10\}$, which are decidedly vicinal to $\{\bar{2}01\}M_2$ or $\{\bar{2}03\}M_1$. The form $\{\bar{2}01\}M_2$, not noted by Moses, is a common form for terlinguaite, and is present on many crystals. The letter x is retained for this simpler form, while m is placed with the unit prism where it belongs. Five other forms have had their indices changed to simpler ones, as some of the symbols given by Moses are very complex and vicinal.

$r\{11.25.25\}$ as given by Moses becomes $\{33.25.25\}$ when changed to the simpler orientation. This form reduces to $\{499\}M_1$ or $\{433\}M_2$, and in fact the angles measured by Moses agree better with the simpler form than they do with the complex one. The form is a prominent one, occurring on six crystals.

Angle values for $r\{433\}M_2$.

	ϕ	ρ
	° ′	° ′
Meas. by Moses........	45 08	70 58
Calc. $\{433\}M_2$..........	45 00	70 45

$i\{7.11.11\}$ becomes $\{21.11.11\}$ in the better orientation. This reduces to $\{233\}M_1$ or $\{211\}M_2$.

Angle values for $i\{211\}M_2$.

	ϕ	ρ
	° ′	° ′
Meas. by Moses........	53 59	74 30
Calc. $\{211\}M_2$..........	55 08	74 14

The form is a prominent one, being present on nine crystals.

$l\{\bar{1}\bar{1}.25.25\}$ as given by Moses becomes in M_2 $\{\bar{3}\bar{3}.25.25\}$, which reduces to $\{\bar{4}99\}M_1$ or $\{\bar{4}33\}M_2$. This form is described as a large striated face, and as found by the writer is a prominent form for this mineral, being seen on eight crystals.

Angle values for $l\{\bar{4}33\}$ M_2.

	ϕ		ρ	
	°	′	°	′
Meas. by Moses........	36	12	68	22
Calc. $\{\bar{4}33\}M_2$..........	36	00	68	13

$g\{\bar{1}\bar{3}.20.20\}$ as given by Moses becomes $\{\bar{3}\bar{9}.20.20\}$ in M_2, which plainly shows that the correct symbol is $\{\bar{2}33\}M_1$ or $\{\bar{2}11\}M_2$. The form, as illustrated by Moses, is the largest pyramid face on the crystal, and as such would hardly have the symbol $\{\bar{3}\bar{9}.20.20\}$.

Angle values for $g\{\bar{2}11\}$ M_2.

	ϕ		ρ	
	°	′	°	′
Meas. by Moses........	48	37	72	02
Calc. $\{\bar{2}11\}M_2$..........	49	12	72	07

It is a prominent form, 22 faces having been measured by the writer.

$\gamma\{\bar{9}77\}$ as given by Moses becomes $\{\bar{2}\bar{7}.7.7\}M_2$, which reduces to $\{\bar{4}33\}M_1$ or $\{\bar{4}11\}M_2$. It is also described as a prominent form for the mineral, and was noticed on 11 crystals.

Angle values for $\gamma\{\bar{4}11\}$ M_2.

	ϕ		ρ	
	°	′	°	′
Meas. by Moses........	67	42	79	28
Calc. $\{\bar{4}11\}M_2$..........	67	50	79	27

The first table below, giving the most common forms, shows only such as were measured at least 10 times—that is, at least 10 different faces of the form were seen on the 12 crystals measured.

Measurements of common forms on terlinguaite crystals.

Letter.	Symbol. M₁	Symbol. M₂	Number of crystals.	Number of measurements.	Average measured. φ	Average measured. ρ	Calculated. φ	Calculated. ρ	Number measured within 5′. φ	Number measured within 5′. ρ	Limits of measurement. φ	Limits of measurement. ρ
					° ′	° ′	° ′	° ′			° ′ ° ′	° ′ ° ′
*j	160	120	10	21	17 58	90 00	17 58	90 00	14	....	17 31 - 18 43	....
m	130	110	10	19	32 57	90 00	32 58	90 00	11	....	32 48 - 33 16	....
*δ	230	210	10	17	52 31	90 00	52 22	90 00	7	....	52 10 - 52 57	....
*D	031	031	8	13	2 38	80 39	2 38	80 40	10	9	2 22 - 2 48	80 25 - 80 46
d	011	011	12	23	7 52	63 56	7 52	63 56	15	17	7 23 - 8 03	63 43 - 64 31
f	013	013	8	16	22 31	36 10	22 30	36 09	7	10	22 01 - 22 47	35 54 - 36 18
h	015	015	10	19	34 36	26 12	34 37	26 12	6	11	33 57 - 34 52	25 52 - 26 30
t	106	102	10	19	90 00	43 05	90 00	43 06	....	15	....	42 57 - 44 36
*L	$\bar{1}$.0.12	$\bar{1}04$	9	10	90 00	2 40	90 00	2 13	....	1	....	2 08 - 2 47
n	$\bar{1}06$	$\bar{1}02$	11	13	90 00	20 35	90 00	20 39	....	7	....	19 19 - 20 47
u	$\bar{1}03$	$\bar{1}01$	11	18	90 00	45 52	90 00	45 56	....	9	....	45 38 - 46 35
*Q	$\bar{1}02$	$\bar{3}02$	10	13	90 00	59 21	90 00	59 23	....	6	....	59 06 - 59 31
*x	$\bar{2}03$	$\bar{2}01$	10	12	90 00	66 52	90 00	66 55	....	6	....	66 16 - 67 06
s	111	311	9	10	64 22	77 56	64 22	77 56	7	9	64 15 - 64 34	77 49 - 78 00
a	$\bar{1}13$	$\bar{3}13$	9	12	56 55	50 56	56 51	50 59	6	4	56 44 - 58 21	50 28 - 51 11
o	$\bar{1}11$	$\bar{3}11$	10	14	61 06	76 35	61 02	76 33	10	8	60 58 - 61 18	76 23 - 76 56
*ε	199	133	10	15	19 31	65 01	19 30	65 02	10	11	18 06 - 19 42	64 44 - 65 10
*Z	166	122	11	15	24 48	65 51	24 49	65 51	5	8	24 21 - 25 13	65 26 - 65 57
p	133	111	12	23	38 09	68 47	38 11	68 47	9	14	36 25 - 38 29	67 46 - 68 54
i	233	211	9	11	55 07	74 13	55 08	74 14	5	7	54 58 - 55 22	74 03 - 74 24
*X	$\bar{1}99$	$\bar{1}33$	7	10	4 35	63 46	4 28	63 47	1	6	4 08 - 4 51	63 15 - 64 04
*ψ	$\bar{1}66$	$\bar{1}22$	10	12	10 34	64 04	10 33	64 06	4	4	10 06 - 10 55	63 37 - 64 18
*Δ	$\bar{2}99$	$\bar{2}33$	8	13	16 23	64 37	16 23	64 39	4	6	16 00 - 16 35	64 02 - 64 54
e	$\bar{1}33$	$\bar{1}11$	10	20	26 55	66 17	27 02	66 15	9	10	26 31 - 27 56	66 06 - 66 33
l	$\bar{4}99$	$\bar{4}33$	8	14	36 01	68 11	36 00	68 13	8	9	35 54 - 36 22	67 59 - 68 32
g	$\bar{2}33$	$\bar{2}11$	11	22	49 13	72 08	49 12	72 07	12	9	48 51 - 49 38	71 52 - 72 34
γ	$\bar{4}33$	$\bar{4}11$	10	14	67 52	79 29	67 50	79 27	4	6	67 39 - 68 08	79 06 - 79 49
π	136	112	8	11	42 40	53 59	42 45	54 02	6	6	42 33 - 42 48	53 41 - 54 17
*O	139	113	11	17	46 42	44 34	46 44	44 33	10	9	46 29 - 46 54	44 11 - 44 52
λ	1.3.15	115	6	10	53 15	34 05	53 15	34 05	4	7	52 45 - 53 57	33 30 - 34 59
*T	239	213	7	10	59 38	53 15	59 42	53 13	6	4	58 58 - 60 11	52 41 - 53 28
β	$\bar{1}$.3.15	$\bar{1}15$	9	12	2 23	22 11	2 25	22 04	3	5	1 02 - 3 52	21 23 - 23 51
*I	$\bar{1}93$	$\bar{1}31$	6	12	9 38	80 46	9 39	80 47	7	6	9 26 - 11 24	79 11 - 80 53
*A	$\bar{2}$.3.21	$\bar{2}17$	6	14	17 52	16 53	18 16	16 56	0	6	15 52 - 20 04	16 10 - 17 14

DESCRIPTION OF LESS COMMON FORMS.

In the following table are given the data for the forms that showed less than 10 faces but more than 2. With these, however, are included the measurements of those forms determined by Moses, to which he gave rather complex symbols.

Occurrence and measurements of less common forms on terlinguaite crystals.

[Bold-faced figures show calculated values. Stars indicate new forms.]

Form and crystal No.	Reflection.	Size of face.	φ	ρ
			° ′	° ′
*B{120}M_1={320}M_2			**44 12**	**90 00**
5	Poor	Minute	44 35	90 00
6	Poor	Minute	44 15	89 50
7	Poor	Small	44 11	90 00
7	Poor	Line face	43 46	90 00
7	Poor	Minute	43 59	90 00
8	Poor	Small	44 07	90 00
9	Poor	Small	44 10	90 00
11	Fair	Medium	44 10	90 00
12	Poor	Small	44 14	90 00
*l{017}M_1={017}M_2			**44 01**	**21 55**
6	Poor	Minute	44 12	21 56
6	Poor	Small	44 03	21 54
9	Poor	Line face	42 28	23 41
11	Poor	Line face	44 37	21 57
*n{1. 0. 15}M_1={105}M_2				**28 28**
6	Exc	Medium		28 28
6	Exc	Medium		28 27
8	Poor	Small		28 27
9	Poor	Line face		28 26
10	Poor	Line face		28 33
11	Poor	Line face		28 30
*p{109}M_1={103}M_2				**35 39**
6	Poor	Minute		34 24
6	Good	Medium		35 34
11	Poor	Minute		35 53
y{103}M_1={101}M_2				**57 52**
1	Poor	Medium		58 05
4	Poor	Minute		57 00
5	Poor	Minute		57 35
6	Poor	Minute		58 00
8	Fair	Small		58 08
10	Poor	Line face		58 04
11	Poor	Minute		58 21
11	Good	Small		57 57
*G{403}M_1={401}M_2				**79 45**
2	Poor	Line face		78 54
9	Fair	Large		79 35
11	Poor	Line face		79 43
12	Good	Line face		78 53

Occurrence and measurements of less common forms on terlinguaite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
*[illegible]($\bar{1}09$)M_1=($\bar{1}03$)M_2				**8 59**
6	Poor	Line face		8 46
8	Poor	Small		8 54
9	Poor	Line face		8 32
11	Poor	Minute		8 55
*x($\bar{1}05$)M_1=($\bar{3}05$)M_2				**26 56**
6	Poor	Minute		26 44
7	Poor	Minute		26 54
9	Poor	Line face		26 44
10	Poor	Line face		26 38
**N*($\bar{2}09$)M_1=($\bar{2}03$)M_2				**30 47**
1	Good	Medium		30 36
1	Poor	Medium		30 45
6	Poor	Line face		30 45
6	Poor	Line face		30 48
7	Fair	Small		31 05
9	Good	Small		30 41
11	Poor	Line face		30 42
*u($\bar{1}04$)M_1=($\bar{3}04$)M_2				**35 11**
6	Poor	Minute		35 09
7	Poor	Small		35 09
9	Poor	Line face		35 04
**Π*($\bar{2}05$)M_1=($\bar{6}05$)M_2				**52 20**
4	Poor	Line face		52 14
6	Fair	Line face		53 08
9	Good	Line face		52 19
10	Poor	Minute		51 26
**P*($\bar{4}09$)M_1=($\bar{4}03$)M_2				**55 47**
1	Poor	Line face		55 44
6	Poor	Minute		55 45
10	Poor	Line face		55 50
z($\bar{1}01$)M_1=($\bar{3}01$)M_2				**74 43**
2	Fair	Minute		74 49
2	Fair	Minute		74 53
4	Fair	Minute		74 37
10	Poor	Small		73 11
11	Poor	Minute		75 34
**S*($\bar{4}03$)M_1=($\bar{4}01$)M_2				**78 38**
3	Poor	Line face		77 56
6	Poor	Minute		78 51
6	Fair	Small		78 33
7	Poor	Medium		78 39
9	Fair	Line face		79 45
9	Fair	Small		79 45
12	Good	Small		78 53

Occurrence and measurements of less common forms on terlinguaite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	φ °	φ ′	ρ °	ρ ′
*** $V\{\bar{1}19\}M_1=\{\bar{3}19\}M_2$**			**35**	**05**	**15**	**22**
1	Poor	Minute	33	59	15	14
1	Fair	Minute	34	56	15	21
3	Poor	Small	36	26	15	02
3	Fair	Line face	35	42	15	20
8	Poor	Line face	36	52	15	40
9	Poor	Line face	35	09	15	24
10	Good	Medium	34	25	15	11
*** $q\{\bar{1}15\}M_1=\{\bar{3}15\}M_2$**			**51**	**27**	**33**	**01**
1	Fair	Small	51	25	32	59
3	Fair	Small	51	35	32	56
6	Poor	Small	51	33	32	59
7	Poor	Minute	51	30	33	01
9	Poor	Minute	51	39	33	00
*** $\mathfrak{G}\{1.30.30\}M_1=\{1.10.10\}M_2$**			**11**	**28**	**64**	**10**
6	Poor	Line face	11	33	64	09
6	Poor	Line face	11	35	64	06
6	Poor	Line face	11	14	63	53
7	Poor	Line face	11	36	64	27
*** $\mathfrak{q}\{1.15.15\}M_1=\{155\}M_2$**			**15**	**00**	**64**	**30**
5	Fair	Line face	15	03	64	30
6	Poor	Line face	14	12	64	27
7	Poor	Line face	15	22	64	42
*** $\zeta\{1.12.12\}M_1=\{144\}M_2$**			**16**	**48**	**64**	**41**
1	Good	Medium	16	46	64	34
6	Fair	Medium	16	43	64	42
6	Fair	Small	16	41	64	46
6	Fair	Small	16	44	64	37
6	Poor	Line face	16	39	64	40
11	Poor	Small	17	01	64	45
*** $Y\{299\}M_1=\{233\}M_2$**			**29**	**42**	**66**	**47**
1	Poor	Minute	29	11	66	50
3	Exc	Minute	29	41	66	51
4	Fair	Minute	29	43	66	44
6	Poor	Minute	29	40	66	46
6	Poor	Minute	29	30	66	33
12	Poor	Line face	29	25	66	36
$r\{499\}M_1=\{433\}M_2$ [a]			**45**	**00**	**70**	**45**
6	Poor	Minute	44	47	69	52
6	Poor	Minute	44	57	70	52
6	Fair	Minute	45	03	70	39
8	Fair	Small	45	11	70	40
9	Poor	Line face	44	59	70	46
10	Poor	Line face	43	40	70	16
11	Poor	Line face	43	37	70	20
12	Fair	Small	45	07	70	42

[a] Given as $\{11.25.25\}M_1=\{33.25.25\}M_2$ by Moses.

Occurrence and measurements of less common forms on terlinguaite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
***$\chi\{122\}M_1=\{322\}M_2$**			**48 00**	**71 43**
1	Fair	Line face	47 53	71 45
3	Exc	Large	47 58	71 44
6	Fair	Small	47 54	71 35
6	Poor	Minute	47 49	71 49
7	Poor	Minute	49 13	72 03
8	Exc	Medium	48 04	71 36
9	Poor	Line face	47 56	71 43
10	Poor	Small	48 07	71 37
12	Poor	Line face	48 06	71 52
***[illegible]$\{599\}M_1=\{533\}M_2$**			**50 38**	**72 36**
6	Poor	Minute	50 24	72 22
8	Fair	Small	50 38	72 31
9	Good	Line face	50 32	72 32
10	Fair	Small	50 40	72 30
$\iota\{233\}M_1=\{211\}M_2$[a]			**55 08**	**74 14**
1	Good	Line face	55 02	74 15
4	Poor	Line face	55 03	74 18
5	Fair	Small	54 58	74 17
6	Poor	Minute	54 59	74 07
6	Fair	Minute	54 57	74 19
7	Poor	Minute	55 22	74 03
8	Fair	Small	55 12	74 09
9	Good	Small	55 01	74 13
10	Fair	Small	55 11	74 07
11	Exc	Medium	55 08	74 17
12	Fair	Small	55 12	74 24
***$\sigma\{\bar{1}.15.15\}M_1=\{\bar{1}55\}M_2$**			**0 29**	**63 43**
5	Poor	Minute	0 00	63 39
5	Exc	Medium	0 32	63 41
6	Poor	Line face	0 00	63 37
6	Poor	Line face	0 00	63 32
6	Fair	Small	0 00	63 37
10	Fair	Small	0 44	63 19
11	Poor	Line face	0 21	63 31
12	Fair	Small	0 18	63 46
***$\phi\{\bar{1}.12.12\}M_1=\{\bar{1}44\}M_2$**			**1 22**	**63 43**
5	Exc	Large	0 32	63 41
6	Poor	Small	1 17	63 39
6	Poor	Line face	1 41	63 37
6	Fair	Line face	1 38	63 31
6	Poor	Small	1 19	63 38
8	Poor	Small	1 26	63 34
11	Poor	Line face	1 09	63 50
11	Poor	Line face	1 55	63 38
11	Poor	Minute	1 21	63 43

[a] Given as $\{7.11.11\}M_1=\{21.11.11\}M_2$ by Moses.

Occurrence and measurements of less common forms on terlinguaite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
*$\mathfrak{T}\{\bar{2}.15.15\}M_1=\{\bar{2}55\}M_2$			**6 55**	**63 53**
7	Poor	Minute	7 19	64 11
8	Good	Medium	7 41	64 01
11	Poor	Line face	6 46	64 00
*$\Gamma\{\bar{1}44\}M_1=\{\bar{3}44\}M_2$			**19 12**	**65 00**
6	Fair	Small	19 14	64 58
6	Poor	Minute	19 23	65 17
6	Fair	Small	19 03	65 02
7	Exc	Medium	19 12	64 59
7	Exc	Large	19 17	65 07
8	Fair	Small	19 16	65 14
9	Fair	Small	19 18	65 02
11	Poor	Minute	19 02	65 00
$l\{\bar{4}99\}M_1=\{\bar{4}33\}M_2{}^a$			**36 00**	**68 13**
1	Poor	Line face	36 04	68 09
1	Poor	Line face	35 39	67 53
2	Poor	Line face	35 57	68 18
4	Poor	Medium	35 57	68 10
4	Good	Line face	35 54	68 10
6	Poor	Line face	36 18	67 51
6	Poor	Line face	36 06	68 11
6	Poor	Line face	35 05	68 12
6	Poor	Minute	35 58	68 16
7	Poor	Minute	36 22	68 32
9	Fair	Medium	36 05	68 18
11	Fair	Medium	36 01	68 16
11	Poor	Minute	35 59	67 59
12	Poor	Line face	34 31	67 34
*$\mathfrak{B}\{137\}M_1=\{337\}M_2$			**44 09**	**50 25**
6	Fair	Small	44 11	50 22
6	Poor	Minute	44 06	50 08
6	Good	Small	44 06	50 23
11	Poor	Line face	44 06	50 31
12	Poor	Line face	44 09	50 14
*$\Sigma\{1.6.12\}M_1=\{124\}M_2$			**30 59**	**49 44**
1	Exc	Minute	31 06	49 45
3	Exc	Medium	30 55	49 46
5	Good	Medium	30 50	49 45
6	Exc	Large	30 46	49 43
6	Exc	Medium	30 52	49 45
6	Good	Large	30 57	49 50
6	Exc	Large	31 05	49 44
11	Poor	Medium	30 55	49 54
12	Good	Medium	30 56	49 45

[a] Given as $\{\bar{1}\bar{1}.25.25\}M_1=\{\bar{3}\bar{3}.25.25\}M_2$ by Moses.

Occurrence and measurements of less common forms on terlinguaite crystals—**Continued.**

Form and crystal No.	Reflection.	Size of face.	ϕ °	ϕ ′	ρ °	ρ ′
*χ{1.6.18}M_1={126}M_2			**36**	**27**	**40**	**00**
6	Fair	Small	36	35	40	01
6	Fair	Small	36	30	40	07
6	Poor	Minute	36	19	40	06
6	Poor	Medium	36	25	40	14
11	Fair	Medium	36	40	40	07
*Φ{1.6.24}M_1={128}M_2			**41**	**14**	**33**	**56**
3	Fair	Minute	41	09	33	59
6	Fair	Minute	41	21	33	57
6	Fair	Minute	41	11	34	02
6	Poor	Medium	41	25	34	02
8	Poor	Minute	40	54	33	20
10	Fair	Small	42	21	33	49
11	Exc	Medium	41	25	34	00
11	Fair	Medium	41	26	34	07
*θ{236}M_1={212}M_2			**57**	**32**	**62**	**04**
1	Poor	Minute	57	33	61	55
9	Poor	Line face	57	30	62	07
9	Poor	Line face	57	51	59	37
10	Poor	Minute	58	28	59	38
12	Poor	Line face	57	36	61	40
*Σ{$\bar{1}$24}M_1={$\bar{3}$24}M_2			**34**	**51**	**50**	**58**
7	Exc	Line face	34	55	50	59
7	Poor	Line face	34	52	51	07
8	Poor	Small	35	00	51	06
9	Exc	Large	35	07	50	58
9	Fair	Line face	35	03	50	57
11	Fair	Medium	34	36	50	52
*ρ{$\bar{1}$39}M_1={$\bar{1}$13}M_2			**13**	**11**	**34**	**44**
1	Fair	Minute	13	19	34	53
3	Fair	Small	13	20	34	46
3	Fair	Minute	13	05	34	45
4	Good	Minute	13	05	34	45
7	Poor	Minute	15	20	35	51
8	Fair	Small	13	39	35	55
9	Fair	Medium	13	17	34	49
11	Poor	Small	12	50	34	46
*H{$\bar{1}$.3.12}M_1={$\bar{1}$14}M_2			**5**	**29**	**26**	**57**
1	Poor	Minute	5	21	25	07
1	Fair	Small	5	14	24	57
3	Fair	Small	5	29	26	56
4	Poor	Minute	6	17	27	01
*ι{$\bar{1}$.6.12}M_1={$\bar{1}$24}M_2			**2**	**45**	**45**	**28**
1	Poor	Minute	2	22	45	40
1	Exc	Medium	2	45	45	20
4	Poor	Line face	2	34	45	36

Occurrence and measurements of less common forms on terlinguaite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
*$J\{\bar{2}.1.15\}M_1=\{\bar{6}.1.15\}M_2$			**61 12**	**15 39**
1	Poor	Minute	62 04	15 44
6	Poor	Minute	61 47	15 31
8	Poor	Minute	61 53	16 03
*$K\{\bar{2}31\}M_1=\{\bar{6}31\}M_2$			**1 18**	**84 07**
4	Fair	Small	51 23	84 07
7	Exc	Large	51 23	84 12
7	Fair	Minute	51 34	84 28
7	Poor	Minute	51 24	84 04
11	Fair	Small	51 20	84 06
*$\Omega\{\bar{2}36\}M_1=\{\bar{2}12\}M_2$			**45 35**	**55 20**
4	Good	Medium	45 32	55 19
5	Fair	Minute	45 57	55 27
9	Fair	Medium	45 49	55 18
*$\xi\{\bar{2}39\}M_1=\{\bar{2}13\}M_2$			**41 26**	**41 59**
3	Fair	Minute	41 20	41 56
7	Poor	Minute	41 31	42 00
8	Exc	Medium	41 22	42 10
9	Fair	Small	41 31	41 59
9	Fair	Medium	41 39	42 01
11	Poor	Small	41 18	41 54
*$\iota\{\bar{2}.3.15\}M_1=\{\bar{2}15\}M_2$			**31 14**	**25 20**
1	Poor	Small	31 13	25 32
1	Poor	Minute	30 36	25 36
3	Fair	Small	31 31	25 13
7	Poor	Minute	31 08	25 18
8	Fair	Medium	31 19	25 30
9	Good	Small	31 20	25 24
11	Fair	Small	30 39	25 21
*$C\{\bar{4}39\}M_1=\{\bar{4}13\}M_2$			**65 21**	**58 17**
1	Good	Small	65 28	58 13
1	Fair	Minute	65 23	58 12
4	Good	Medium	65 16	58 13
4	Poor	Minute	65 21	58 28
5	Fair	Minute	65 43	58 21
7	Poor	Minute	65 20	58 29
8	Fair	Medium	65 15	58 30
9	Good	Medium	65 25	58 14
*$\mathfrak{B}\{\bar{4}.3.15\}M_1=\{\bar{4}15\}M_2$			**62 17**	**41 08**
1	Poor	Minute	62 16	40 58
6	Poor	Minute	62 14	41 03
7	Poor	Line face	62 21	41 25
9	Good	Small	62 31	41 00

Occurrence and measurements of less common forms on terlinguaite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ		ρ	
			°	′	°	′
*$\mathfrak{A}\{\bar{4}.3.33\}M_1=\{\bar{4}.1.11\}M_2$			**47**	**08**	**15**	**07**
6	Poor	Minute	47	29	14	55
6	Fair	Small	47	23	15	05
6	Poor	Minute	46	44	15	00
8	Poor	Minute	48	30	15	33
9	Fair	Small	46	59	15	07
*$\mathfrak{G}\{\bar{4}.9.15\}M_1=\{\bar{4}35\}M_2$			**82**	**89**	**55**	**16**
7	Exc	Large	32	25	55	13
7	Poor	Medium	32	29	55	24
9	Poor	Line face	32	37	55	17
11	Poor	Medium	32	15	55	10
*$E\{\bar{5}39\}M_1=\{\bar{5}13\}M_2$			**70**	**81**	**68**	**45**
1	Good	Small	70	34	63	38
3	Poor	Minute	70	34	63	43
7	Poor	Minute	70	34	63	57
7	Poor	Minute	70	48	63	58
8	Fair	Small	70	24	63	54
9	Poor	Minute	70	38	63	39
10	Fair	Small	70	08	63	23
*$\Gamma\{\bar{5}.3.15\}M_1=\{\bar{5}15\}M_2$			**68**	**86**	**47**	**59**
1	Fair	Minute	68	36	47	59
7	Fair	Small	68	30	48	12
9	Good	Medium	68	51	47	54
10	Fair	Small	67	52	47	44
*$\mathfrak{N}\{\bar{5}.3.27\}M_1=\{\bar{5}19\}M_2$			**68**	**21**	**26**	**88**
1	Poor	Minute	64	12	27	23
6	Poor	Minute	63	38	26	33
9	Poor	Minute	63	40	26	39
10	Fair	Small	61	38	26	33
*$\mathfrak{Q}\{\bar{5}.6.12\}M_1=\{\bar{5}24\}M_2$			**58**	**22**	**59**	**29**
1	Poor	Minute	53	21	59	30
1	Poor	Minute	53	23	59	20
7	Poor	Minute	53	23	59	25
8	Poor	Minute	53	14	59	37

DESCRIPTION OF RARE FORMS.

Finally, the following table shows the rare forms, such as occurred only once or twice:

Occurrence and measurements of rare forms (all new), terlinguaite crystals.

Letter.	Symbol.		Crystal No.	Reflection.	Size of face.	Measured.		Calculated.	
	M_1.	M_2.				ϕ	ρ	ϕ	ρ
						° ′	° ′	° ′	° ′
b	290	230	1	Poor....	Minute........	23 28	90 00	23 23	90 00
m	560	520	4	Good....	Small.........	58 21	90 00	58 20	90 00
d	890	830	9	Poor....	Small.........	60 10	90 00	59 58	90 00
r	210	610	2	Poor....	Minute........	76 20	90 00	75 35	90 00
f	045	045	6	Poor....	Line face......	9 46	58 51	9 48	58 41
g	035	035	6	Poor....	Line face......	13 04	50 56	12 58	51 16
g	035	035	6	Fair.....	Minute........	13 46	49 38	12 58	51 16
h	012	012	6	Fair.....	Minute........	15 24	46 34	15 26	46 24
a	049	049	6	Fair.....	Minute........	17 23	43 04	17 15	43 18
a	049	049	6	Poor....	Minute........	16 46	44 08	17 15	43 18
b	025	025	6	Poor	Minute........	19 33	39 53	19 03	40 35
n	1.0.12	104	6	Good....	Small.........	0 00	32 49	0 00	31 18
n	1.0.12	104	11	Poor....	Small.........	0 00	31 15	0 00	31 18
j	108	308	11	Poor....	Minute........	0 00	37 29	0 00	37 40
r	209	203	2	Poor....	Line face......	0 00	48 21	0 00	49 07
r	209	203	9	Fair.....	Small.........	0 00	49 03	0 00	49 07
N	104	304	2	Poor....	Line face......	0 00	51 58	0 00	51 39
N	104	304	11	Poor....	Small.........	0 00	51 22	0 00	51 39
s	409	403	10	Poor....	Minute........	0 00	63 47	0 00	63 46
s	409	403	11	Poor....	Minute........	0 00	63 53	0 00	63 46
F	509	503	1	Poor....	Small.........	0 00	67 49	0 00	67 56
F	509	503	1	Poor....	Line face......	0 00	67 44	0 00	67 56
W	101	301	6	Poor....	Minute........	0 00	76 54	0 00	76 40
W	101	301	11	Poor....	Line face......	0 00	75 40	0 00	76 40
q	301	901	8	Good....	Medium.......	0 00	85 27	0 00	85 16
q	301	901	10	Poor....	Line face......	0 00	84 56	0 00	85 16
k	401	12.0.1	6	Poor....	Minute........	0 00	86 34	0 00	86 26
M	$\bar{1}$.0.21	$\bar{1}$07	3	Poor....	Minute........	0 00	4 58	0 00	5 16
R	$\bar{4}$.0.15	$\bar{4}$05	7	Poor....	Line face......	0 00	37 36	0 00	37 37
B	$\bar{5}$09	$\bar{5}$03	7	Fair.....	Minute........	0 00	62 16	0 00	62 21
B	$\bar{5}$09	$\bar{5}$03.	12	Exc	Small.........	0 00	62 28	0 00	62 21
C	$\bar{5}$06	$\bar{5}$02	6	Poor....	Minute........	0 00	71 28	0 00	71 35
C	$\bar{5}$06	$\bar{5}$02	10	Poor....	Line face......	0 00	71 10	0 00	71 35
θ	$\bar{5}$03	$\bar{5}$01	7	Poor....	Line face......	0 00	81 09	0 00	80 58
Z	$\bar{7}$03	$\bar{7}$01	2	Poor....	Line face......	0 00	83 54	0 00	83 36
J	$\bar{4}$01	$\bar{12}$.0.1	9	Poor....	Minute........	0 00	86 32	0 00	86 18
c	117	317	11	Poor....	Line face......	71 57	41 54	71 03	41 41
U	$\bar{1}$.1.11	$\bar{3}$.1.11	1	Poor....	Line face......	24 26	11 10	23 05	11 19
U	$\bar{1}$.1.11	$\bar{3}$.1.11	1	Fair.....	Minute........	23 05	11 19	23 05	11 19
ι	1.24.24	188	5	Fair.....	Line face......	12 24	64 12	12 25	64 15
H	1.18.18	166	7	Poor....	Line face......	13 30	64 37	13 10	64 23
K	144	344	6	Poor....	Minute........	31 56	67 21	31 59	67 16
O	433	411	6	Poor....	Line face......	69 56	80 23	69 54	80 22
O	433	411	10	Poor....	Small.........	69 54	80 17	69 54	80 22
ω	$\bar{1}$55	$\bar{3}$55	4	Good....	Medium.......	14 02	64 24	14 05	64 24
ω	$\bar{1}$55	$\bar{3}$55	6	Fair.....	Small.........	15 14	64 27	14 05	64 24
J	$\bar{2}$77	$\bar{6}$77	1	Poor....	Minute........	21 03	65 19	22 40	65 30
J	$\bar{2}$77	$\bar{6}$77	7	Poor....	Minute........	22 27	65 34	22 40	65 30
K	$\bar{1}$22	$\bar{3}$22	5	Fair.....	Minute........	40 05	69 22	39 51	69 14
K	$\bar{1}$22	$\bar{3}$22	8	Fair.....	Minute........	38 08	68 39	39 51	69 14
G	$\bar{5}$66	$\bar{5}$22	6	Poor....	Minute........	56 08	74 40	55 57	74 32
T	126	326	6	Good....	Small.........	54 17	49 09	54 09	49 03
T	126	326	11	Poor....	Line face......	53 08	48 21	54 09	49 03
V	128	328	10	Poor....	Small.........	56 31	43 33	56 45	42 43
A	193	131	1	Poor....	Minute........	14 03	81 16	14 41	80 57
A	193	131	1	Poor....	Minute........	14 35	80 57	14 41	80 57
W	232	632	3	Good....	Minute........	55 01	78 52	54 15	79 07
[illegible]	2.3.15	215	6	Poor....	Small.........	61 40	42 07	63 17	42 00
[illegible]	2.3.15	215	6	Poor....	Small.........	62 21	42 06	63 17	42 00
ϑ	1.4.14	3.4.14	6	Poor....	Line face......	43 51	39 16	44 07	38 52
ϑ	1.4.14	3.4.14	6	Poor....	Line face......	44 00	39 07	44 07	38 52
Ξ	$\bar{1}$34	$\bar{3}$34	6	Poor....	Minute........	26 15	59 33	24 54	59 03
μ	$\bar{2}$32	$\bar{6}$32	7	Poor....	Line face......	50 20	77 33	50 18	78 07
m	$\bar{2}$35	$\bar{6}$35	4	Poor....	Line face......	46 29	60 41	46 47	60 35
m	$\bar{2}$35	$\bar{6}$35	5	Fair.....	Minute........	47 09	60 42	46 47	60 35
x	$\bar{2}$.3.18	$\bar{2}$16	11	Poor....	Line face......	24 54	19 52	25 05	20 26
Y	$\bar{8}$.3.12	$\bar{8}$14	2	Poor....	Minute........	77 42	67 30	77 48	67 20

DOUBTFUL AND VICINAL FORMS.

Below is given a list of nine doubtful forms, some of them vicinal. As, however, the reflections, though poor, could be measured with fair accuracy, the measurements are given for the different forms. Some of them show the vicinal form of the indices better when transformed into new orientations.

{029} M_1 or {029} M_2: This dome was observed but once, as a minute face, on crystal 6. The measured angles vary considerably from the values calculated for {029}, but agree well with those calculated for the more complex symbol {0.3.13}.

Angle values for {029} M_2.

	ϕ		ρ	
	°	′	°	′
Measured...............	30	50	28	37
Calculated for {029}......	31	51	27	54
Calculated for {0.3.13}...	30	54	28	34

The symbol {0.3.13} is a rather unusual one, however, and the number 13 does not occur in any other form of terlinguaite. The form is therefore referred to {029} and classed as doubtful.

{503} M_1 or {501} M_2 is probably the correct symbol for a form measured on four faces, on as many different crystals, but the measurements gave such varying results, that, until better verified, the form is classed as doubtful.

Occurrence and measurements of {503} M_1 or {501} M_2.

Crystal No.	Reflection.	Size of face.	ρ (81° 41′ calc.).	
			°	′
1	Poor.....	Medium..........	83	04
2	Poor.....	Line face.........	80	51
10	Poor.....	Line face.........	82	27
11	Poor.....	Minute...........	80	25

{$\bar{1}\bar{3}$.0.36} M_1 or {$\bar{1}\bar{3}$.0.12} M_2 is a form doubtless best considered as vicinal to {$\bar{1}$01} M_2. It was noticed twice on crystal 6 with the following measurements:

	°	′
Calculated (ρ)...	48	48
Measured (1)...	48	51
Measured (2)...	48	46

{114} M_1 or {314} M_2 occurs on three crystals, on two accompanied by a vicinal form. The measurements of the different faces

vary considerably, and they are therefore grouped together under this one head, and the form is considered as doubtful.

Occurrence and measurements of {114} M_1 or {314} M_2.

Crystal No.	Reflection.	Size of face.	ϕ (68° 11′ calc.).		ρ (54° 43′ calc.).	
			°	′	°	′
6	Fair.....	Small	65	55	53	35
10	Good....	Medium........	66	49	53	39
10	Poor.....	Line face.......	70	41	54	05
11	Poor.....	Line face.......	65	51	53	39
11	Poor.....	Line face.......	69	44	55	04

{477} M_1 or {12.7.7} M_2 occurs twice on two crystals, the measurements showing almost identical values, which, however, are not very close to the calculated.

Occurrence and measurements of {477} M_1 or {12.7.7} M_2.

Crystal No.	Reflection.	Size of face.	ϕ (51° 20′ calc.).		ρ (72° 51′ calc.).	
			°	′	°	′
9	Poor.....	Line face.......	51	51	72	56
10	Poor.....	Line face.......	51	52	72	54

{533} M_1 or {511} M_2 was observed once as a minute face, the measured and calculated angles not agreeing well. The face is present on crystal 1 and gave a poor reflection.

Angle values of {533} M_1 or {511} M_2.

	ϕ		ρ	
	°	′	°	′
Calculated.............	73	00	82	01
Measured.............	73	04	81	07

{$\bar{5}$08} M_1 or {$\bar{1}\bar{5}$.0.8} M_2, and {$\bar{7}$.0.10} M_1 or {$\bar{2}\bar{1}$.0.10} M_2, both given by Moses, are considered vicinal to {$\bar{2}$03}, to which the letter x has been assigned. Moses describes {$\bar{7}$.0.10} as occurring twice, once as a striation and the second time as a large face (shown in his fig. 3). The latter is undoubtedly {$\bar{2}$03}, which form is not given by Moses. A line face was observed by the writer on crystal 2, measurement of which placed it near the form {$\bar{5}$08}, but it is considered vicinal.

{$\bar{3}$.2.18} M_1 or {$\bar{9}$.2.18} M_2 was observed twice on crystal 1, as minute faces giving fair reflections.

Angle values of {3.2.18} M_1 or {9.2.18} M_2.

	ϕ	ρ
	° ′	° ′
Calculated............	59 10	23 42
Measured (1)..........	59 04	23 39
Measured (2)..........	60 20	24 24

$\{\bar{9}.8.18\}\,M_1$ or $\{\bar{27}.7.18\}\,M_2$ was also noted twice, on two crystals, Nos. 1 and 3, giving poor reflections.

Angle values of {$\bar{9}$.8.18} M_1 or {$\bar{27}$.7.18} M_2.

	ϕ	ρ
	° ′	° ′
Calculated............	61 58	62 25
Measured (1)..........	62 11	62 14
Measured (3)..........	62 34	61 35

DISCUSSION OF FORMS.

Prism zone (No. 1),[a] symbol, $\frac{h}{k}$.

Form.............	b	j	$\mathfrak{u}$	m	B	ζ	$\mathfrak{m}$	$\mathfrak{d}$	$\mathfrak{r}$	a
	010	120	230	110	320	210	520	830	610	100
Symbol...........	0	1/2	2/3	1	3/2	2	5/2	8/3	6	∞
N_3...............	0	1/2	2/3	1	3/2	2	(5/2)	[8/3]	(6)	∞

In place of 8/3 we should expect 3 or {310}. The measurement shows, however, that {830} is the correct symbol:

	° ′
ϕ calculated for (310)..	62 48
ϕ calculated for (830)..	59 58
ϕ measured..	60 10

Two other forms are extra. The last three forms show the following characteristics:

{520} occurs once; small face; good reflection; Δ[b] = 01′.
{830} occurs once; small face; poor reflection; Δ = 12′.
{610} occurs once; minute face; poor reflection; Δ = 45′.

The angles between the nearest forms for {610} are: (100):(610) = 14° 25′; and (830):(610) = 15° 37′; so that {610} must be taken as the correct symbol. The face occurred in the prism zone with ζ, m, j, b, j', ζ'.

All three forms are considered as established, the zone showing a marked disturbance in the vicinity of the orthopinacoid, it being

[a] See gnomonic projection, Pl. V, for relations of zones.
[b] The sign Δ means the difference between measured and calculated angles.

again noted that the extra forms are nearest the form with the simplest indices, namely, {100}.

Clinodome zone (No. 2); symbol, $\frac{k}{l}$.

Form.........	*c*	𝔩	*h*	—	*f*	𝔟	𝔞	𝔥	𝔤	𝔣	*d*	*D*	*b*
	001	017	015	029	013	025	049	012	035	045	011	031	010
Symbol.......	0	1/7	1/5	2/9	1/3	2/5	4/9	1/2	3/5	4/5	1	3	∞

Dividing the series at 1/3, and letting v in any row represent the member in the preceding row:

$3v$............	0	3/7	3/5	2/3	1
$\frac{v}{1-v}$..........	0	3/4	3/2	2	∞
$\frac{2}{3}v$	0	1/2	1	4/3	∞
N_2............	0	1/2	1	(4/3) .	∞

	1/3	2/5	4/9	1/2	3/5	4/5	1	3	∞
$\frac{v-v_1}{v_2-v}$..	0	1/6	1/5	1/3	2/3	7/3	∞		
$3v$.....	0	1/2	3/5	1	2	7	∞		
N_2.....	0	1/2	(3/5)	1	2	(7)	∞		

{029}, {049}, and {045} do not fit in, all three being extra.

{029} occurs once as a minute face, $\Delta_\phi = 1° \; 01'$; $\Delta_\rho = 0° \; 43'$. The form is doubtful. (See p. 108.)

{049} occurs twice as minute faces. The best measurement agrees fairly closely with the calculated angles. {045} occurs once as a line face, $\Delta_\phi = 02'$; $\Delta_\rho = 10'$. The agreement between the measured and calculated angles is good for these two forms, so that both are considered as established. The two forms {049} and {045}, which cause a disturbance in the otherwise normal series (the doubtful form {029} being excluded), are near to the simple forms {012} and {011}.

Positive orthodome zone (No. 3a); symbol, $\frac{h}{l}$.

Form..............................	*c*	𝔫	𝔬	𝔭	𝔧	*t*	𝔯	𝔑	*y*
	001	105	104	103	308	102	203	304	101
Symbol..............................	0	1/5	1/4	1/3	3/8	1/2	2/3	3/4	1
N_4..............................	0	(1/5)	1/4	1/3	[3/8]	1/2 .	2/3	3/4	1
Form..............................	𝔰	*F*	*w*	*G*	—	*η*	𝔨		*a*
	403	503	301	401	501	901	12.0.1		100
Symbol..............................	4/3	5/3	3	4	5	9	12		∞
N_1..............................	4/3 .	5/3 . .	3	4	(5)	(9)	(12)		∞

In place of 3/8 we would expect 2/5, but the measured angles agree better with 3/8.

Calculated........	3/8=37° 40′	Measured.........	37° 29′
Calculated........	2/5=38 49		

Dividing the series at 1 and considering the first part:

	0	1/5	1/4	1/3	3/8	1/2	2/3	3/4	1
$\frac{v}{1-v}$....................	0	1/4	1/3	1/2	3/5	1	2	3	∞

Dividing again at 1:

	0	1/4	1/3	1/2	3/5	1
$\frac{v}{1-v}$....	0	1/3	1/2	1	3/2	∞
N_2......	0	1/3	1/2 .	1	3/2 . .	∞

	1	2	3	∞
$v-1$................	0	1	2	∞
N_2................	0 .	1	2	∞

The first part of the entire zone from {001} to {101} is normal.

The second part of the original series gives:

	1	4/3	5/3	3	4	5	9	12	∞
$v-1$	0	1/3	2/3	2	3	4	8	11	∞
N_3	0	1/3 .	2/3 . .	2	3	(4)	(8)	(11)	∞
$\frac{v}{2}$				1	3/2	2	4	11/2	∞
$v-1$				0	1/2	1	3	9/2	∞
N_2				0	1/2	1 .	(3)	(9/2)	∞

The form 3 or {901} does not fit in. In its place we would expect {701}. The measurements show, however, that {901} is the correct symbol:

	° ′
Calculated {901}	85 16
Calculated {701}	83 58
Measured (1)	85 27
Measured (2)	84 56

The form must therefore be considered as established.

{12.0.1} is extra. It occurred but once as a minute face; $\Delta = 8'$.

{501}, though fitting well in the series, must be classed as doubtful for the present. The form is present on four crystals, but the angles vary considerably, Δ amounting to $+1°\ 23'$, $-1°\ 50'$, $+0°\ 46'$, and $-1°\ 16'$. (See p. 108 for angles.) It is possible that more forms than one are here grouped under {501}.

The zone shows the results of disturbance near the orthopinacoid in the presence of {901} and {12.0.1}, which do not fit into the normal series.

Negative orthodome zone (No. 3b); symbol, $-\frac{h}{l}$.

Form	c	M	L	$\mathfrak{M}$	n	$\mathfrak{x}$	N	$\mathfrak{y}$	R	u	—
	001	$\bar{1}07$	$\bar{1}04$	$\bar{1}03$	$\bar{1}02$	$\bar{3}05$	$\bar{2}03$	$\bar{3}04$	$\bar{4}05$	$\bar{1}01$	$\overline{13}.0.12$
Symbol	0	1/7	1/4	1/3	1/2	3/5	2/3	3/4	4/5	1	13/12
N_4	0	(1/7)	1/4	1/3 .	1/2	3/5	2/3	3/4	(4/5)	1	(13/12)

Form	Π	P	Q	$\mathfrak{B}$	x	$\mathfrak{C}$	z	S	θ	$\mathfrak{Z}$	$\mathfrak{J}$	a
	$\bar{6}05$	$\bar{4}03$	$\bar{3}02$	$\bar{5}03$	$\bar{2}01$	$\bar{5}02$	$\bar{3}01$	$\bar{4}01$	$\bar{5}01$	$\bar{7}01$	$\overline{12}.0.1$	$\bar{1}00$
Symbol	6/5	4/3	3/2	5/3	2	5/2	3	4	5	7	12	∞
N_4	(6/5)	4/3	3/2	5/3	2	5/2	3	4	(5)	(7)	(12)	∞

The only missing number is 2/5; otherwise the series is complete for N_4. As a whole, the zone is nearly normal, several extra forms being present.

Dividing the series at 1 and considering only the first part:

	0	1/7	1/4	1/3	1/2	3/5	2/3	3/4	4/5	1
$\frac{v}{1-v}$	0	1/6	1/3	1/2	1	3/2	2	3	4	∞
N_3	0	(1/6)	1/3	1/2 .	1	3/2	2	3	(4)	∞

Again dividing at 1:

	0	1/6	1/3	1/2	1
$\frac{v}{1-v}$	0	1/5	1/2	1	∞
N_2	0	(1/5)	1/2	1 .	∞

	1	3/2	2	3	4	∞
$v-1$	0	1/2	1	2	3	∞
N_2	0	1/2	1	2	(3)	∞

These results show that neither (1/5) representing $\{\bar{1}07\}$ nor (4/5) representing $\{\bar{4}05\}$ fit into the normal series, and that no benefit results in further reducing the series N_3.

$\{\bar{1}07\}$ occurs but once, as a minute face; $\Delta = 18'$.
$\{\bar{4}05\}$ occurs but once, as a line face; $\Delta = 01'$.

Both forms are considered as established. Here again these extra forms in an otherwise normal series are nearest the end members with simplest indices, $\{001\}$ and $\{\bar{1}01\}$.

Considering now the second portion of the original series:

	1	13/12	6/5	4/3	3/2	5/3	2	5/2	3	4	5	7	12	∞
$v-1$.	0	1/12	1/5	1/3	1/2	2/3	1	3/2	2	3	4	6	11	∞
N_3...	0	(1/12)	(1/5)	1/3	1/2	2/3	1	3/2	2	3	(4)	(6)	(11)	∞

Dividing the series at 1 we have:

	0	1/12	1/5	1/3	1/2	2/3	1
$\frac{v}{1-v}$.	0	1/11	1/4	1/2	1	2	∞
N_2..	0	(1/11)	(1/4)	1/2	1	2	∞

	1	3/2	2	3	4	6	11	∞
$v-1$...	0	1/2	1	2	3	5	10	∞
N_2.....	0	1/2	1	2	(3)	(5)	(10)	∞

These results show that (13/12), (6/5), (5), (7), and (12) do not fit into the normal series, a result obtained also by a consideration of the series N_3.

$\{\bar{6}05\}$ is a well-established form, occurring on four crystals.

$\{\bar{5}01\}$ is present but once; $\Delta = 11'$. $\{\bar{7}01\}$ occurs once as a line face; $\Delta = 18'$. $\{\overline{12}.0.1\}$ occurs once as a minute face; $\Delta = 14'$. All three are established forms.

The form $\{\overline{13}.0.12\}$ is a doubtful one. The angles agree fairly closely, but from its occurrence the form can not be considered as an established one (see p. 108).

The results obtained by splitting the series N_4 into smaller series is the same as that obtained by considering the series N_4, and shows that, of the negative orthodomes, the following do not fit in the normal series: $\{\bar{1}07\}$, $\{\bar{4}05\}$, $\{\bar{6}05\}$, $\{\bar{5}01\}$, $\{\bar{7}01\}$, $\{\overline{12}.0.1\}$.

The zone shows disturbances near the base and orthopinacoid, and also near the unit dome.

Diagonal zone $(\bar{1}11):(001):(1\bar{1}1)$ *(No. 4); symbol,* $\frac{h}{l}$.

Form..	e	Ξ	ρ	H	β	c	λ	O	$\mathfrak{M}$	π	k	p
	$\bar{1}11$	$\bar{3}34$	$\bar{1}13$	$\bar{1}14$	$\bar{1}15$	001	$1\bar{1}5$	$1\bar{1}3$	$3\bar{3}7$	$1\bar{1}2$	$3\bar{3}4$	$1\bar{1}1$
Symbol.	$\bar{1}$	$\bar{3}/4$	$\bar{1}/3$	$\bar{1}/4$	$\bar{1}/5$	0	1/5	1/3	3/7	1/2	3/4	1

Dividing the series at $\bar{1}/3$ or $\{\bar{1}13\}$:

	$\bar{1}/3$	$\bar{1}/4$	$\bar{1}/5$	0	1/5	1/3	3/7	1/2	3/4	1
$v+1$................	2/3	3/4	4/5	1	6/5	4/3	10/7	3/2	7/4	2
$\frac{v-v_1}{v_2-v}$................	0	1/15	1/9	1/3	2/3	1	4/3	5/3	13/3	∞
$3v$................	0	1/5	1/3	1	2	3	4	5	13	∞

Again dividing the series at 1:

	0	1/5	1/3	1
$\frac{v}{1-v}$	0	1/4	1/2	∞
$2v$	0	1/2	1	∞
N_2	0	1/2	1 .	∞

	1	2	3	4	5	13	∞
$v-1$	0	1	2	3	4	12	∞
$\frac{v}{2}$	0	1/2	1	3/2	2	6	∞
N_3	0 .	1/2 .	1	3/2	2 .	(6)	∞

The only form which does not fit in is {334}—a rare form not found by the writer, but noted by Moses.

The first part of the original zone from ($\bar{1}11$) to (001) gives:

	c	β	H	ρ	Ξ	e
	0	$\bar{1}/5$	$\bar{1}/4$	$\bar{1}/3$	$\bar{3}/4$	$\bar{1}$
$\frac{v}{1-v}$	0	1/4	1/3	1/2	3	∞
N_3	0	(1/4)	1/3	1/2	3	∞

	c	β	H	ρ	Ξ	e
	0	$\bar{1}/5$	$\bar{1}/4$	$\bar{1}/3$	$\bar{3}/4$	$\bar{1}$
$v+1$	1	4/5	3/4	2/3	1/4	0
$\frac{v}{1-v}$	∞	4	3	2	1/3	0
$\frac{v}{2}$	∞	2	3/2	1	1/6	0
N_2	∞	2	(3/2)	1 .	(1/6)	0

Positive pyramid zone (100):(111):(011) (No. 5a); symbol, $\frac{h}{l}$.

Form	d	$\mathfrak{G}$	τ	$\mathfrak{T}$	$\mathfrak{q}$	ζ	ε	Z	v	Y	$\mathfrak{K}$
	011	1.10.10	188	166	155	144	133	122	355	233	344
Symbol	0	1/10	1/8	1/6	1/5	1/4	1/3	1/2	3/5	2/3	3/4
N_4	0	(1/10)	(1/8)	(1/6)	(1/5)	1/4	1/3 .	1/2	3/5	2/3	3/4
Form	p	r	χ	$\mathfrak{M}$	—	i	s	$\mathfrak{O}$	—	a	
	111	433	322	533	12.7.7	211	311	411	511	100	
Symbol	1	4/3	3/2	5/3	12/7	2	3	4	5	∞	
N_4	1	4/3	3/2	5/3	(12/7)	2 .	3	4	(5)	∞	

Dividing the series at 1 and considering the first part:

	0	1/10	1/8	1/6	1/5	1/4	1/3	1/2	3/5	2/3	3/4	1
$\frac{v}{1-v}$	0	1/9	1/7	1/5	1/4	1/3	1/2	1	3/2	2	3	∞

Again dividing at 1:

	0	1/9	1/7	1/5	1/4	1/3	1/2	1
$\frac{v}{1-v}$	0	1/8	1/6	1/4	1/3	1/2	1	∞
$2v$	0	1/4	1/3	1/2	2/3	1	2	∞
N_3	0	(1/4)	1/3	1/2	2/3	1 .	2 .	∞

	1	3/2	2	3	∞
$v-1$	0	1/2	1	2	∞
N_2	0	1/2	1	2	∞

In the second division the zone is normal. Dividing the first division again at 1:

	0	1/4	1/3	1/2	2/3	1
$\frac{v}{1-v}$	0	1/3	1/2	1	2	∞
N_3	0	1/3	1/2 .	1 .	2 .	∞

The zone, though incomplete, is normal.

The result shows that, by redividing, all of the members of the first part of the series N_4 can be made to fit into a normal series. The four members that do not belong in the first part of N_4 as normal members have the following characteristics:

{1.10.10} occurs on two crystals as line faces.

{188} occurs once as a line face; $\Delta\varphi=01'$; $\Delta\rho=03'$.

{166} occurs once as a line face; $\Delta\varphi=20'$; $\Delta\rho=14'$.

{155} occurs on three crystals, but always as line faces.

Considering now the second part of the series N_4:

	1	4/3	3/2	5/3	12/7	2	3	4	5	∞
$v-1$	0	1/3	1/2	2/3	5/7	1	2	3	4	∞
N_2	0	1/3	1/2	2/3	(5/7)	1 .	2 .	3	(4)	∞

Dividing the series at 1:

	0	1/3	1/2	2/3	5/7	1
$\frac{v}{1-v}$	0	1/2	1	2	5/2	∞
N_2	0	1/2	1	2	(5/2)	∞

	1	2	3	4	∞
$v-1$	0	1	2	3	∞
$\frac{v}{2}$	0	1/2	1	3/2	∞
N_2	0	1/2	1	[3/2]	∞

5/2 or {12.7.7} is a vicinal form to {533}, occurring once each on two crystals, on both accompanied by {533}.

Angle values for the forms {12.7.7} and {533}.

Form.	Measured.		Calculated.	
	ϕ	ρ	ϕ	ρ
	° ′	° ′	° ′	° ′
{12.7.7}	51 51 51 52	72 56 72 54	51 20	72 51
{533}	....	....	50 38	72 36

The form 3/2 or {511} occurred once as a minute face. We would expect 2 or {611}. The angles measured vary from those calculated for {511} and agree almost as well with those for the form {922}.

Angle values for form of doubtful symbol.

	ϕ	ρ
	° ′	° ′
Calculated for {922}...	71 53	81 16
Calculated for {511}...	73 31	82 01
Measured	73 04	81 07

The symbol is therefore in doubt.

The entire zone shows a strong disturbance near the unit clinodome {011}, and also slightly near the orthopinacoid, as can be seen best by the series N_4.

Negative pyramid zone ($\bar{1}00$) : ($\bar{1}11$) : (011) (No. 5b); symbol, $-\frac{h}{l}$.

Form...	d 011	σ $\bar{1}55$	ϕ $\bar{1}44$	X $\bar{1}33$	$\mathfrak{L}$ $\bar{2}55$	ψ $\bar{1}22$	ω $\bar{3}55$	Δ $\bar{2}33$	Γ 344	$\mathfrak{J}$ $\bar{6}77$	e $\bar{1}11$	l $\bar{4}33$	$\mathfrak{K}$ $\bar{3}22$	g $\bar{2}11$	$\mathfrak{S}$ $\bar{5}22$	o 311	γ $\bar{4}11$	a $\bar{1}00$
Symbol.	0	1/5	1/4	1/3	2/5	1/2	3/5	2/3	3/4	6/7	1	4/3	3/2	2	5/2	3	4	∞
N_4......	0	(1/5)	1/4	1/3	2/5	1/2	3/5	2/3	3/4	(6/7)	1	4/3	3/2 .	2	5/2	3	4	∞

This zone is very nearly a perfect normal series N_4, with only one member missing and two extra.

Of the forms which do not fit in the normal series, (1/5) or $\{\bar{1}55\}$ is well established. This is shown by dividing the series at 1 and reducing the first part:

	0	1/5	1/4	1/3	2/5	1/2	3/5	2/3	3/4	6/7	1
$\frac{v}{1-v}$	0	1/4	1/3	1/2	2/3	1	3/2	2	3	6	∞

Dividing at 1:

	0	1/4	1/3	1/2	2/3	1
$\frac{v}{1-v}$	0	1/3	1/2	1	2	∞

	1	3/2	2	3	6	∞
$v-1$	0	1/2	1	2	5	∞
N_2	0	1/2	1	2	(5)	∞

Dividing the first division again at 1:

	0	1/3	1/2	1
$\frac{v}{1-v}$	0	1/2	1	∞
N_2	0	1/2	1 .	∞

The only member that does not fit in is $\{\bar{6}77\}$ a rare form near to $\{\bar{3}44\}$.

Angle values for the form $\{\bar{3}44\}$.

	ϕ		ρ	
	°	′	°	′
Calculated $\{\bar{3}44\}$	19	12	65	00
Calculated $\{\bar{6}77\}$	22	40	65	34
Measured (1)	21	03	65	19
Measured (2)	22	27	65	34

The second part of the zone N_4 is normal and, in fact, the entire zone shows very little disturbance. Both extra forms are nearest the simplest indices, namely, $\{011\}$ and $\{\bar{1}11\}$.

Pyramid zone, $\frac{k}{l}=\frac{1}{5}$ *(No. 6); symbol,* $\frac{h}{l}$.

Form	a	$\mathfrak{W}$	λ	h	β	$\mathfrak{t}$	q	$\mathfrak{B}$	r	a
	100	215	115	015	$\bar{1}15$	$\bar{2}15$	$\bar{3}15$	$\bar{4}15$	$\bar{5}15$	$\bar{1}00$
Symbol	∞	2/5	1/5	0	$\bar{1}/5$	$\bar{2}/5$	$\bar{3}/5$	$\bar{4}/5$	$\bar{1}$	$\bar{\infty}$

Dividing at 0:

	0	1/5	2/5	∞
$5v$	0	1	2	∞
N_2	0 .	1	2	∞

	0	$\bar{1}/5$	$\bar{2}/5$	$\bar{3}/5$	$\bar{4}/5$	$\bar{1}$	$\bar{\infty}$
$\bar{5}v$	0	1	2	3	4	5	∞
$\frac{v}{2}$	0	1/2	1	3/2	2	5/2	∞
N_2	0	1/2	1	(3/2)	2	(5/2)	∞
$v-1$		0	1/2	1	(3/2)	∞	
N_2		0	1/2	1 .	(3/2)	∞	

The series is normal with an extra form.

Pyramid zone, $\frac{k}{l}=\frac{1}{3}$ *(No. 7); symbol,* $\frac{h}{l}$.

Form	a	$\mathfrak{N}$	$\mathfrak{m}$	α	ξ	ρ	f	$\mathfrak{X}$	O	$\mathfrak{T}$	T	a
	$\bar{1}00$	$\bar{5}13$	$\bar{4}13$	$\bar{3}13$	$\bar{2}13$	$\bar{1}13$	013	126	113	326	213	100
Symbol	∞	$\bar{5}/3$	$\bar{4}/3$	$\bar{1}$	$\bar{2}/3$	$\bar{1}/3$	0	1/6	1/3	1/2	2/3	∞
$v+1$	∞	$\bar{2}/3$	$\bar{1}/3$	0	1/3	2/3	1	7/6	4/3	3/2	5/3	∞

Dividing at 1 and reversing the first half:

	1	2/3	1/3	0	$\bar{1}/3$	$\bar{2}/3$	∞
$v-1$	0	1/3	2/3	1	4/3	5/3	∞

Dividing again at 1:

	0	1/3	2/3	1
$\frac{v}{1-v}$	0	1/2	2	∞
N_2	0	1/2	. 2	∞

	1	4/3	5/3	∞
$v-1$	0	1/3	2/3	∞
$3v$	0	1	2	∞
N_2	0	. 1	2	∞

The second half of the original zone gives:

	1	7/6	4/3	3/2	5/3	∞
$3v$	3	7/2	4	9/2	5	∞
$v-3$	0	1/2	1	3/2	2	∞
N_2	0	1/2	1	(3/2)	2	∞

Dividing again at 1, the second part gives:

	1	3/2	2	∞
$v-1$	0	1/2	1	∞
N_2	0	1/2	1 .	∞

The zone can thus be reduced to smaller series and shown to be entirely normal.

Pyramid zone, $\frac{k}{l}=\frac{1}{2}$ (No. 8); symbol, $\frac{h}{l}$.

Form	*a*	*θ*	*π*	*Σ*	$\mathfrak{h}$	*ι*	$\mathfrak{Z}$	*Ω*	$\mathfrak{P}$	*a*
	∞	212	112	124	012	$\bar{1}24$	$\bar{3}24$	$\bar{2}12$	$\bar{5}24$	$\bar{1}00$
Symbol	∞	1	1/2	1/4	0	$\bar{1}/4$	$\bar{3}/4$	$\bar{1}$	$\bar{5}/4$	∞

Dividing the series at 0:

	∞	1	1/2	1/4	0
Reversing	0	1/4	1/2	1	∞
$2v$	0	1/2	1	2	∞
N_2	0	1/2	1	2	∞

	0	$\bar{1}/4$	$\bar{3}/4$	$\bar{1}$	$\bar{5}/4$	$\bar{\infty}$
$4v$	0	$\bar{1}$	$\bar{3}$	$\bar{4}$	$\bar{5}$	$\bar{\infty}$
$v+1$	1	0	$\bar{2}$	$\bar{3}$	$\bar{4}$	8
$\frac{v}{2}$		0	1	3/2	2	∞
$v-1$			0	1/2	1	∞
N_2			0	1/2	1 .	∞

The zone is normal.

Pyramid zone $(1\bar{1}1):(102):(011)$ (No. 9); symbol, $\frac{h}{l}$.

Form	*d*	*Σ*	*O*	$\mathfrak{M}$	$\mathfrak{P}$	$\mathfrak{E}$	*t*	*ξ*	*e*
	011	124	113	328	215	317	102	$2\bar{1}3$	$1\bar{1}1$
Symbol	0	1/4	1/3	3/8	2/5	3/7	1/2	2/3	1
$\frac{v}{1-v}$	0	1/3	1/2	3/5	2/3	3/4	1	2	∞

Dividing at 1:

	0	1/3	1/2	3/5	2/3	3/4	1
$\frac{v}{1-v}$	0	1/2	1	3/2	2	3	∞
N_2	0 .	1/2 .	1	3/2	2	3	∞

The zone is normal.

Pyramid zone (310) : (001) : ($\bar{3}\bar{1}0$) (No. 10); symbol, $\frac{h}{l}$.

Form	*s*	—	*r*	*c*	*U*	*V*	*q*	*α*	*o*
	311	314	317	001	$\bar{3}.\bar{1}.11$	$\bar{3}\bar{1}9$	$\bar{3}\bar{1}5$	$\bar{3}\bar{1}3$	$\bar{3}\bar{1}1$
Symbol	3	3/4	3/7	0	$\bar{3}$/11	$\bar{1}$/3	$\bar{3}$/5	$\bar{1}$	$\bar{3}$

Dividing the series at 0 or {001}:

	3	3/4	3/7	0		0	3/11	1/3	3/5	1	3
$\frac{v}{3-v}$	∞	1/3	1/6	0	$\frac{v}{3-v}$	0	1/10	1/8	1/4	1/2	∞
$3v$	∞	1	1/2	0	$4v$	0	2/5	1/2	1	2	∞
N_2	∞ .	1	1/2	0	N_2	0	(2/5)	1/2	1	2	∞

The series is normal, 2/5 or {$\bar{3}$.1.11} being extra. Though rare, the form is considered as established.

Pyramid zone ($1\bar{2}2$) : (001) : ($\bar{1}22$) (No. 11); symbol, $\frac{k}{l}$.

Form	*Z*	*Σ*	*X*	*Φ*	*c*	*ι*	*Υ*	*j*
	$1\bar{2}2$	$1\bar{2}4$	$1\bar{2}6$	$1\bar{2}8$	001	$\bar{1}24$	$\bar{1}22$	$\bar{1}20$
Symbol	$\bar{1}$	$\bar{1}$/2	$\bar{1}$/3	$\bar{1}$/4	0	1/2	1	∞
$v+1$	0	1/2	2/3	3/4	1	3/2	2	∞
N_3	0 .	1/2	2/3	(3/4)	1	3/2	2 .	∞
$\frac{v}{1-v}$	0	1	2	3	∞			
$\frac{v}{2}$	0	1/2	1	3/2	∞			
N_2	0	1/2	1	[3/2]	∞			

In place of 3/2 we would expect 2 or {1.$\bar{2}$.10}. The form {$1\bar{2}8$} is, however, well established.

Pyramid zone ($1\bar{1}1$) : ($0\bar{1}3$) : ($\bar{1}02$) (No. 12); symbol, $\frac{k}{l}$.

Form	*e*	*ι*	*f*	*β*	*A*	*V*	*𝔄*	*J*	*n*	*𝔅*	*α*	*Q*	*g*
	$1\bar{1}1$	$1\bar{2}4$	$0\bar{1}3$	$\bar{1}\bar{1}5$	$\bar{2}\bar{1}7$	$\bar{3}\bar{1}9$	$\bar{4}.\bar{1}.11$	$\bar{6}.\bar{1}.15$	$\bar{1}02$	$\bar{4}15$	$\bar{3}13$	$\bar{5}24$	$\bar{2}11$
Symbol	$\bar{1}$	$\bar{1}$/2	$\bar{1}$/3	$\bar{1}$/5	$\bar{1}$/7	$\bar{1}$/9	$\bar{1}$/11	$\bar{1}$/15	0	1/5	1/3	1/2	1

Dividing the series at 0 and considering only the first part, reversing:

	0	$\bar{1}$/15	$\bar{1}$/11	$\bar{1}$/9	$\bar{1}$/7	$\bar{1}$/5	$\bar{1}$/3	$\bar{1}$/2	$\bar{1}$
$3v$	0	1/5	3/11	1/3	3/7	3/5	1	3/2	3

Dividing again at 1:

	0	1/5	3/11	1/3	3/7	3/5	1		1	3/2	3 (∞)
$\frac{v}{1-v}$	0	1/4	3/8	1/2	3/4	3/2	∞	$v-1$	0	1/2	2 (∞)
$\frac{4}{3}v$	0	1/3	1/2	2/3	1	2	∞	N_2	0	1/2 .	2 (∞)
N_3	0	1/3	1/2	2/3	1 .	2 .	∞				

The second part of the original zone gives:

	0	1/5	1/3	1/2	1
$\frac{v}{1-v}$	0	1/4	1/2	1	∞
$2v$	0	1/2	1	2	∞
N_2	0	1/2	1	2	∞

The entire zone is thus shown to be normal.

Pyramid zone (211) : (001) : ($\bar{2}\bar{1}1$) (*No. 13*); *symbol*, $\frac{k}{l}$.

Form	δ	W	i	θ	T	$\mathfrak{Y}$	c	A	$\mathfrak{n}$	$\mathfrak{t}$	ξ	Ω	$\mathfrak{m}$	g	u	K	δ
	210	632	211	212	213	215	001	$\bar{2}\bar{1}7$	$\bar{2}\bar{1}6$	$\bar{2}\bar{1}5$	$\bar{2}\bar{1}3$	$\bar{2}\bar{1}2$	$\bar{6}\bar{3}5$	$\bar{2}\bar{1}1$	$\bar{6}\bar{3}2$	$\bar{6}\bar{3}1$	$\bar{2}\bar{1}0$
Symbol	∞	3/2	1	1/2	1/3	1/5	0	$\bar{1}/7$	$\bar{1}/6$	$\bar{1}/5$	$\bar{1}/3$	$\bar{1}/2$	$\bar{3}/5$	$\bar{1}$	$\bar{3}/2$	$\bar{3}$	$\overline{\infty}$
$v+1$	∞	5/2	2	3/2	4/3	6/5	1	6/7	5/6	4/5	2/3	1/2	2/5	0	$\bar{1}/\bar{2}$	$\bar{2}$	$\overline{\infty}$

Dividing at 1 and at 0, the first part gives:

	∞	5/2	2	3/2	4/3	6/5	1
$v-1$	∞	3/2	1	1/2	1/3	1/5	0
Reversing	0	1/5	1/3	1/2	1	3/2	∞
N_3	0	(1/5)	1/3	1/2 .	1	3/2 . .	∞
	0	1/5	1/3	1/2	1		
$\frac{v}{1-v}$	0	1/4	1/2	1	∞		
$2v$	0	1/2	1	2	∞		
N_2	0	1/2	1	2	∞		

The second part gives:

	1	6/7	5/6	4/5	2/3	1/2	2/5	0
$\frac{v}{1-v}$	∞	6	5	4	2	1	2/3	0
Reversing	0	2/3	1	2	4	5	6	∞
$\frac{v}{2}$	0	1/3	1/2	1	2	5/2	3	∞
N_3	0	1/3	1/2 .	1 .	2	(5/2)	3	∞
$v-1$				0	1	3/2	2	∞
$v-1$					0	1/2	1	∞
N_2					0	1/2	1 .	∞

The last part gives:

	g	u	K	δ
$\bar{v}$	0	1/2	2	∞
N_2	0	1/2 .	2	∞

The zone is entirely normal.

Pyramid zone (011) : (102) : ($\bar{1}\bar{1}1$) (*No. 14*); *symbol*, $\frac{k}{l}$.

Form	d	ι	ρ	$\mathfrak{t}$	n	$\mathfrak{X}$	q	ξ	$\mathfrak{Z}$	—	e
	011	$\bar{1}24$	$\bar{1}13$	$\bar{2}15$	$\bar{1}02$	$5\bar{1}9$	$\bar{3}\bar{1}5$	$\bar{2}\bar{1}3$	$\bar{3}\bar{2}4$	$\bar{4}\bar{3}5$	$\bar{1}\bar{1}1$
Symbol	1	1/2	1/3	1/5	0	$\bar{1}/9$	$\bar{1}/5$	$\bar{1}/3$	$\bar{1}/2$	$\bar{3}/5$	$\bar{1}$
$v+1$	2	3/2	4/3	6/5	1	8/9	4/5	2/3	1/2	2/5	0
Reversing and $\frac{v}{2}$	0	1/5	1/4	1/3	2/5	4/9	1/2	3/5	2/3	3/4	1
$\frac{v}{1-v}$	0	1/4	1/3	1/2	2/3	4/5	1	3/2	2	3	∞
N_3	0	(1/4)	1/3	1/2	2/3	(4/5)	1	3/2	2	3	∞

Dividing the series at 1, we have:

	0	1/4	1/3	1/2	2/3	4/5	1
$\frac{v}{1-v}$	0	1/3	1/2	1	2	4	∞
N_3	0	1/3	1/2 .	1 .	2 .	(4)	∞

	1	3/2	2	3	∞
$v-1$	0	1/2	1	2	∞
N_2	0	1/2 .	1	2	∞

The form 4 or {$5\bar{1}9$} is extra. Occurring on three crystals, the form is, however, well established.

Pyramid zone, $\frac{h}{l}=2$ *(No. 15); symbol,* $\frac{k}{l}$.

Form	g $\bar{2}11$	$\mathfrak{K}$ $\bar{8}14$	x $\bar{2}01$	$\mathfrak{K}$ $\bar{8}\bar{1}4$	g $\bar{2}\bar{1}1$
Symbol	1	1/4	0	$\bar{1}$/4	$\bar{1}$
$\frac{v-v_1}{v_2-v}$	0	3/5	1	5/3	∞
N_2	0	[3/5]	1	[5/3]	∞

Instead of 3/5 and 5/3 we would expect 1/2 and 2 or $\{\bar{6}13\}$. The relation can be better shown by changing the symbols to M_1, giving $\{\bar{8}.3.12\}$ M_1. $\{\bar{8}.4.12\}$ M_1 would make the series normal.

Angle values for $\{8.3.12\}$ M_1.

	ϕ		ρ	
	°	′	°	′
Calc. $\{\bar{8}.3.12\}$	77	48	67	20
Calc. $\{\bar{8}.4.12\}$	73	57	67	43
Measured	77	42	67	30
Δ		06		10

The measurement shows, however, that $\{\bar{8}.3.12\}$ M_1 or $\{\bar{8}14\}$ M_2 is the correct symbol.

Positive pyramid zone (010) : (101) (No. 16); symbol, $\frac{k}{l}$.

Form	b 010	A 131	p 111	θ 212	y 101
Symbol	∞	3	1	1/2	0
N_2	∞	[3]	1	1/2	0

In place of 3 or {131} we would expect 2 or {121}, but {131} is the correct symbol.

Negative pyramid zone, $\frac{h}{l}=\frac{1}{3}$ *(No. 17); symbol,* $\frac{k}{l}$.

Form	b 010	ε $\bar{1}33$	O $\bar{1}13$	$\mathfrak{n}$ $\bar{2}16$	V $\bar{3}19$	[illegible] $\bar{1}03$
Symbol	∞	1	1/3	1/6	1/9	0
$3v$	∞	3	1	1/2	1/3	0
N_3	∞	3 . .	1 .	1/2	1/3	0

The zone is normal, though incomplete.

Negative pyramid zone $\frac{h}{l}=1$ *(No. 18); symbol,* $\frac{k}{l}$.

Form	I $\bar{1}31$	e $\bar{1}11$	Ω $\bar{2}12$	α $\bar{3}13$	Γ $\bar{5}15$	u $\bar{1}01$
Symbol	3	1	1/2	1/3	1/5	0
$\frac{v}{v-1}$	3/2	∞	1	1/2	1/4	0
$2v$		∞	2	1	1/2	0
N_2		∞	2	1	1/2	0

The zone is normal.

Pyramid zone (10$\bar{2}$) : (01$\bar{2}$) (No. 19); symbol, $\frac{k}{l}$.

Form	t 102	s 3.4.14	𝔛 126	𝔥 012	ϕ $\bar{1}$22
Symbol	0	2/7	1/3	1/2	1
$\frac{v}{v-1}$	0	2/5	1/2	1	∞
N_2	0	(2/5)	1/2	1	∞

The form 2/5 or {3.4.14} is extra. The form, though rare, is well established.

Combinations of forms on terlinguaite crystals.

No.	Letter.	Symbol (M_2).	Crystal No.— 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	*c*	001	c	c	c	c	c	c	c	c	c	c	c	....
2	*b*	010	b	b	b	....	b	b	b	....	b	....	b	b
3	*a*	100	a	a	a	a	a	a	a	a	a	a	a	a
4	*j*	120	....	j	j	j	j	j	j	....	j	j	j	j
5	𝔲	230	𝔲	....	....	....	....	....	....	....	....	....	....	....
6	*m*	110	....	m	m	m	m	m	m	m	m	....	m	m
7	*B*	320	....	....	....	....	B	B	B	B	B	....	B	B
8	∂	210	∂	∂	∂	∂	∂	....	∂	∂	∂	....	∂	∂
9	𝔪	520	....	....	....	𝔪	....	....	....	....	....	....	....	....
10	𝔡	830	....	....	....	....	....	....	....	....	𝔡	....	....	....
11	𝔢	610	....	𝔢	....	....	....	....	....	....	....	....	....	....
12	*D*	031	D	D	D	D	....	D	D	....	....	....	D	D
13	*d*	011	d	d	d	d	d	d	d	d	d	d	d	d
14	𝔣	045	....	....	....	....	....	𝔣	....	....	....	....	....	....
15	𝔤	035	....	....	....	....	....	𝔤	....	....	....	....	....	....
16	𝔥	012	....	....	....	....	....	𝔥	....	....	....	....	....	....
17	𝔞	049	....	....	....	....	....	𝔞	....	....	....	....	....	....
18	𝔟	025	....	....	....	....	....	𝔟	....	....	....	....	....	....
19	*f*	013	f	f	f	....	....	f	f	f	f	....	f	....
	?	029	....	....	....	....	....	*	....	....	....	....	....	....
20	*h*	015	h	h	h	h	h	h	....	h	h	h	h	....
21	𝔩	017	....	....	....	....	....	𝔩	....	....	𝔩	....	𝔩	....
22	𝔫	105	....	....	....	....	....	𝔫	....	𝔫	𝔫	𝔫	𝔫	....
23	𝔬	104	....	....	....	....	....	𝔬	....	....	....	....	𝔬	....
24	𝔭	103	....	....	....	....	....	𝔭	....	....	....	....	𝔭	....
25	𝔧	308	....	....	....	....	....	....	....	....	....	....	𝔧	....
26	*t*	102	t	t	t	t	t	t	....	t	t	t	t	....
27	𝔯	203	....	𝔯	....	....	....	....	....	....	𝔯	....	....	....
28	𝔑	304	....	𝔑	....	....	....	....	....	....	....	....	𝔑	....
29	*y*	101	y	....	....	y	y	y	....	y	....	y	y	....
30	𝔰	403	....	....	....	....	....	....	....	....	....	𝔰	𝔰	....
31	*F*	503	F	....	....	....	....	....	....	....	....	....	....	....
32	*w*	301	....	....	....	....	....	w	....	....	....	....	w	....
33	*G*	401	....	G	....	....	....	....	....	....	G	....	G	G
	?	501	*	*	....	....	....	....	....	....	....	*	*	....
34	*η*	901	....	....	....	....	....	....	....	η	....	η	....	....
35	𝔨	12.0.1	....	....	....	....	....	𝔨	....	....	....	....	....	....
36	*M*	$\bar{1}$07	....	....	M	....	....	....	....	....	....	....	....	....
37	*L*	$\bar{1}$04	L	....	L	L	L	L	....	L	L	L	L	....
38	𝔐	$\bar{1}$03	....	....	....	....	....	𝔐	....	𝔐	𝔐	....	𝔐	....
39	*n*	$\bar{1}$02	n	n	n	n	n	n	....	n	n	n	n	n
40	𝔵	$\bar{3}$05	....	....	....	....	....	𝔵	𝔵	....	𝔵	𝔵	....	....

Combinations of forms on terlinguaite crystals—Continued.

No.	Letter.	Symbol (M_2).	Crystal No.—											
			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
41	*N*	$\bar{2}03$	N	....	....	....	....	N	N	....	N	....	N	....
42	𝔫	$\bar{3}04$	....	....	....	....	....	𝔫	𝔫	....	𝔫	....	....	....
43	*R*	$\bar{4}05$	....	....	....	....	....	....	R	....	....	....	....	....
44	*u*	$\bar{1}01$	u	u	u	u	u	u	....	u	u	u	u	u
	?	$1\bar{2}.0.11$	....	....	....	....	....	*	....	....	....	....	....	....
45	*Π*	605	....	....	....	*Π*	....	*Π*	....	....	*Π*	*Π*	....	....
46	*P*	$\bar{4}03$	P	....	....	....	....	P	....	....	....	P	....	....
47	*Q*	$\bar{5}02$	Q	Q	Q	Q	Q	Q	Q	....	Q	....	Q	Q
48	𝔔	$\bar{5}03$	....	....	....	....	....	....	𝔔	....	....	....	....	....
49	*x*	$\bar{2}01$	x	x	....	x	x	....	x	x	x	x	x	x
50	ℭ	$\bar{5}02$	....	....	....	....	....	ℭ	....	....	....	ℭ	....	....
51	𝔷	$\bar{3}01$	....	𝔷	....	𝔷	....	....	....	....	....	𝔷	𝔷	....
52	*S*	$\bar{4}01$	....	....	S	....	....	S	S	....	S	....	....	S
53	*θ*	$\bar{5}01$	....	....	....	....	....	....	*θ*	....	....	....	....	....
54	𝔷	$\bar{7}01$	....	𝔷	....	....	....	....	....	....	....	....	....	....
55	𝔍	$\overline{12}.0.1$	....	....	....	....	....	....	....	....	𝔍	....	....	....
56	𝔯	317	....	....	....	....	....	....	....	....	....	....	𝔯	....
	?	314	....	....	....	....	....	*	....	....	....	*	*	....
57	𝔰	311	𝔰	....	𝔰	....	𝔰	𝔰	....	𝔰	𝔰	𝔰	𝔰	𝔰
58	*U*	$\bar{3}.1.11$	U	....	....	....	....	....	....	....	....	....	....	....
59	*V*	$\bar{3}19$	V	....	V	....	....	....	....	V	V	V	....	....
60	*q*	$\bar{3}15$	q	....	q	....	....	q	q	....	q	....	....	....
61	*α*	$\bar{3}13$	*α*	*α*	*α*	*α*	*α*	*α*	*α*	*α*	*α*	....	....	....
62	*o*	$\bar{3}11$	o	o	o	o	....	o	o	o	o	....	o	o
63	𝔊	1.10.10	....	....	....	....	....	𝔊	𝔊	....	....	....	....	....
64	*τ*	188	....	....	....	....	*τ*	....	....	....	....	....	....	....
65	𝔗	166	....	....	....	....	....	....	𝔗	....	....	....	....	....
66	𝔮	155	....	....	....	....	𝔮	𝔮	𝔮	....	....	....	....	....
67	*ζ*	144	*ζ*	....	....	....	....	*ζ*	....	....	....	....	*ζ*	....
68	*ε*	133	*ε*	....	*ε*	*ε*	*ε*	*ε*	*ε*	*ε*	*ε*	*ε*	....	*ε*
69	*Z*	122	....	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z
70	*v*	355	....	....	....	....	....	....	....	....	....	....	....	....
71	*Y*	233	Y	....	Y	Y	....	Y	....	....	....	....	....	Y
72	𝔎	344	....	....	....	....	....	𝔎	....	....	....	....	....	....
73	*p*	111	p	p	p	p	p	p	p	p	p	p	p	p
74	*r*	433	....	....	....	....	....	r	....	r	r	r	r	r
75	*χ*	322	*χ*	....	*χ*	....	....	*χ*	*χ*	*χ*	*χ*	*χ*	....	*χ*
76	𝔐	533	....	....	....	....	....	𝔐	....	𝔐	𝔐	𝔐	....	....
	?	12.7.7	....	....	....	....	....	....	....	....	*	*	....	....
77	*i*	211	i	....	....	i	i	i	i	i	i	i	i	i
78	𝔒	411	....	....	....	....	....	𝔒	....	....	....	𝔒	....	....
	?	511	*	....	....	....	....	....	....	....	....	....	....	....
79	*σ*	$\bar{1}55$	....	....	....	....	*σ*	*σ*	....	....	....	*σ*	*σ*	*σ*
80	*φ*	$\bar{1}44$	....	....	....	....	*φ*	*φ*	....	*φ*	....	....	*φ*	....
81	*X*	$\bar{1}33$	....	....	....	....	*X*	*X*	*X*	....	*X*	*X*	*X*	*X*
82	𝔏	$\bar{2}55$	....	....	....	....	....	....	𝔏	𝔏	....	....	𝔏	....
83	*ψ*	$\bar{1}22$	*ψ*	*ψ*	*ψ*	....	*ψ*	*ψ*	*ψ*	....	*ψ*	*ψ*	*ψ*	*φ*
84	*ω*	$\bar{3}55$	....	....	....	*ω*	....	*ω*	....	....	....	....	....	....
85	*Δ*	$\bar{2}33$	*Δ*	....	....	....	....	*Δ*	*Δ*	*Δ*	*Δ*	*Δ*	*Λ*	*Δ*

Combinations of forms on terlinguaite crystals—Continued.

No.	Letter.	Symbol (M_2).	Crystal No.—											
			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
86	Γ	$\bar{3}44$	Γ	....	....	....	....	Γ	Γ	Γ	Γ	Γ	....	....
87	𝔍	$\bar{6}77$	𝔍	....	....	....	....	....	𝔍	....	....	....	....	....
88	e	$\bar{1}11$	e	e	....	e	e	e	e	e	e	....	e	e
89	l	$\bar{4}33$	l	l	....	l	....	l	l	....	l	....	l	l
90	ℜ	$\bar{3}22$	....	....	....	....	ℜ	....	....	ℜ	....	....	....	....
91	g	$\bar{2}11$	g	g	g	g	g	g	g	g	g	....	g	g
92	𝔊	$\bar{5}22$	....	....	....	....	....	𝔊	....	....	....	....	....	....
93	r	$\bar{4}11$	....	r	r	r	....	r	r	r	r	r	r	r
94	𝔗	326	....	....	....	....	....	𝔗	....	....	....	....	𝔗	....
95	𝔓	328	....	....	....	....	....	....	....	....	....	𝔓	....	....
96	k	334	....	....	....	....	....	....	....	....	....	....	....	....
97	π	112	π	π	π	....	π	π	....	....	π	....	π	π
98	𝔑	337	....	....	....	....	....	𝔑	....	....	....	....	𝔑	𝔑
99	O	113	O	....	O	O	O	O	O	O	O	O	O	O
100	λ	115	λ	....	....	....	....	λ	....	λ	λ	λ	λ	....
101	s	3. 4. 14	....	....	....	....	....	s	....	....	....	....	....	....
102	Σ	124	Σ	....	Σ	....	Σ	Σ	....	....	....	....	Σ	Σ
103	𝔛	126	....	....	....	....	....	𝔛	....	....	....	....	𝔛	....
104	Φ	128	....	....	Φ	....	....	Φ	....	Φ	....	Φ	Φ	....
105	Λ	131	Λ	....	....	....	....	....	....	....	....	....	....	....
106	W	632	....	....	W	....	....	....	....	....	....	....	....	....
107	θ	212	θ	....	....	....	....	....	....	....	θ	θ	....	θ
108	T	213	T	....	....	....	....	T	....	T	T	T	T	T
109	𝔘	215	....	....	....	....	....	𝔘	....	....	....	....	....	....
110	ℨ	$\bar{3}24$	....	....	....	....	....	....	ℨ	ℨ	ℨ	....	ℨ	....
111	Ξ	$\bar{3}34$	....	....	....	....	....	Ξ	....	....	....	....	....	....
112	ρ	$\bar{1}13$	ρ	....	ρ	ρ	....	....	ρ	ρ	ρ	....	ρ	....
113	H	$\bar{1}14$	H	....	H	H	....	....	....	....	....	....	....	....
114	β	$\bar{1}15$	β	....	β	β	β	β	....	β	β	β	β	....
115	ι	$\bar{1}24$	ι	....	....	ι	....	....	....	....	....	....	....	....
116	I	$\bar{1}31$	....	I	....	I	....	I	I	....	....	....	I	I
117	J	$\bar{6}.1.15$	J	....	....	....	....	J	....	J	....	....	....	....
118	K	$\bar{6}31$	....	....	....	K	....	....	K	....	....	....	K	....
119	μ	$\bar{6}32$	....	....	....	....	....	....	μ	....	....	....	....	....
120	𝔪	$\bar{6}35$	....	....	....	𝔪	𝔪	....	....	....	....	....	....	....
121	Ω	$\bar{2}12$	....	....	....	Ω	Ω	....	....	....	Ω	....	....	....
122	ξ	$\bar{2}13$	....	....	ξ	....	....	....	ξ	ξ	ξ	....	ξ	....
123	𝔱	$\bar{2}15$	𝔱	....	𝔱	....	....	....	𝔱	𝔱	𝔱	....	𝔱	....
124	𝔫	$\bar{2}16$	....	....	....	....	....	....	....	....	....	....	𝔫	....
125	A	$\bar{2}17$	....	....	....	A	....	A	....	A	A	A	A	....
126	C	$\bar{4}13$	C	....	....	C	C	....	C	C	C	....	....	....
127	𝔅	$\bar{4}15$	𝔅	....	....	....	....	𝔅	𝔅	....	𝔅	....	....	....
128	𝔄	$\bar{4}.1.11$	....	....	....	....	....	𝔄	....	𝔄	𝔄	....	....	....
129	𝔈	$\bar{4}35$	....	....	....	....	....	....	𝔈	....	𝔈	....	𝔈	....
130	E	$\bar{5}13$	E	....	E	....	....	....	E	E	E	E	....	....
131	r	$\bar{5}15$	r	....	....	....	....	....	r	....	r	r	....	....
132	𝔑	$\bar{5}19$	𝔑	....	....	....	....	𝔑	....	....	𝔑	𝔑	....	....
133	𝔔	$\bar{5}24$	𝔔	....	....	....	....	....	𝔔	𝔔	....	....	....	....
134	𝔍	$\bar{8}14$	....	𝔍	....	....	....	....	....	....	....	....	....	....

ZONAL RELATIONS AND GNOMONIC PROJECTION.

There are two very prominent zones for terlinguaite, namely the zone of orthodomes, with 36 forms, and the pyramid zone (100):(011):($\bar{1}$00), with 33 forms. Only the first one, the zone of orthodomes, is characteristically striated, all the faces of this zone showing the horizontal striæ more or less developed. Many of these domes, especially among the rare forms, invariably occur as line faces, though quite a number are commonly present as narrow faces, as large as many of the pyramids. The pyramid zone (100):(011) is in some instances partly striated, though generally the faces of these forms are perfectly smooth. Between (144) and (011) were noted striations, among which the forms {155}, {166}, {188}, and {1.10.10} were determined. The large face of {$\bar{3}$55} or {$\bar{1}$22} on terlinguaite crystal 4, shown in figure 25, is strongly striated.

All the forms lie in well developed zones, whose relation can be best seen in the gnomonic projection here shown. The actual zones in which the forms lie can also be noted in the discussion of the forms just given. In this discussion the zones are numbered to correspond to the numbers as given on the zones in the projection of Plate V. Some of the pyramid zones, especially the negative ones, not only are well developed, but also show a great regularity in the indices of the various forms. Thus in the four pyramid zones, given below, the variable number in the symbols increases regularly by 1, and there are only two exceptions to the completeness of all four series.

Table of zones showing regularity of symbols.

013	024	015	$\bar{1}$10
$\bar{1}$13	$\bar{1}$24	$\bar{1}$15	$\bar{1}$11
$\bar{2}$13	—	$\bar{2}$15	($\bar{1}1\frac{4}{3}$)
$\bar{3}$13	$\bar{3}$24	$\bar{3}$15	$\bar{1}$13
$\bar{4}$13	$\bar{4}$24	$\bar{4}$15	$\bar{1}$14
$\bar{5}$13	$\bar{5}$24	$\bar{5}$15	$\bar{1}$15

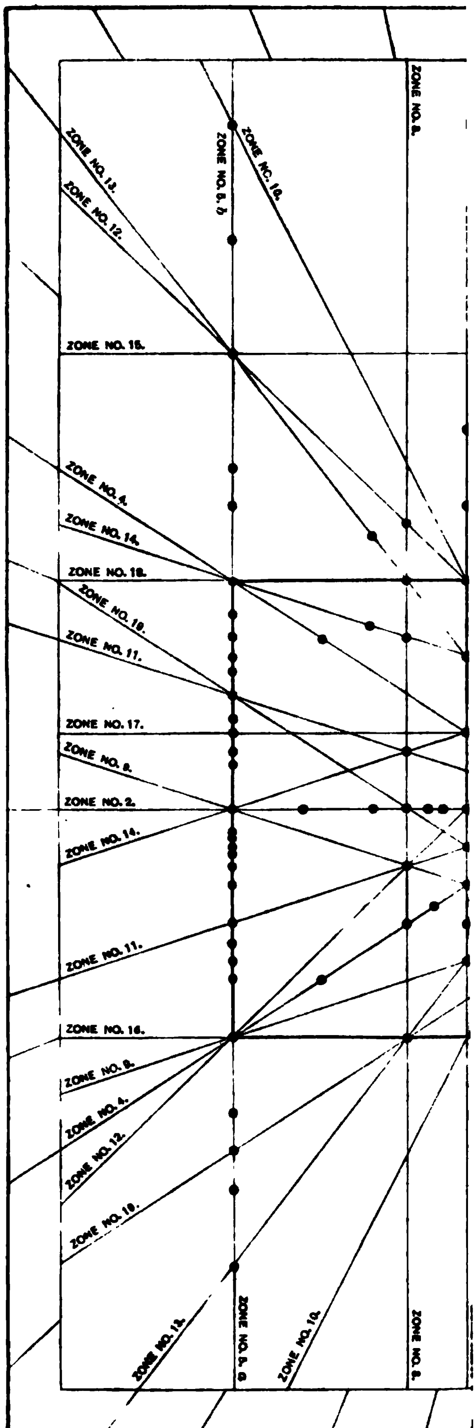
In the following two zones the variable number increases by 2 instead of by 1, except for the positive part of the second zone, where the number changes by 3:

(1)			$\bar{1}$24	$\bar{1}$22	120	122	124	126	128
(2)	$\bar{3}$.1.11	$\bar{3}$19	—	$\bar{3}$15	$\bar{3}$13	$\bar{3}$11	311	314	317

An odd zone, and one that is usually well developed on these crystals, is the negative zone (013):($\bar{1}$02), with the forms—

013 $\bar{1}$15 $\bar{2}$17 $\bar{3}$19 $\bar{4}$.1.11 —— $\bar{6}$.1.15 $\bar{1}$02

in which only {$\bar{5}$.1.13} is missing. Other pyramids lie in this zone, but on the other side of (013) and ($\bar{1}$02), respectively, and notwithstanding the complexity of some of the forms, for example {$\bar{4}$.1.11}, the zone is entirely normal, as shown on p. 118.



GNOMONIC PROJ

The accompanying gnomonic projection (Pl. V) shows the distribution of the forms and zonal relations better than a text description can. Though 134 forms have been determined, a glance at the gnomonic projection shows that a number of forms of very simple indices have not as yet been found, such as {130}, {310}, {201}, {302}, {021}, {$\bar{1}$12}, etc. The measurement of more crystals will undoubtedly considerably extend the present list of forms, and in time terlinguaite will come to rank in the very first class of those minerals possessing an extraordinary richness of combination. It may be stated here that the forms are fairly well distributed over the entire crystal, no one zone having the greater number of forms, as given for epidote, for example, by Zambonini,[a] who enumerates 299 forms, of which over half, or 173, belong to the orthodome zone. The distribution of forms for terlinguaite is shown below:

Distribution of forms of terlinguaite.

Pinacoids	3	Positive pyramids *hhl*	5
Prisms	8	Negative pyramids *hhl*	4
Clinodomes	10	Positive pyramids *hkl*	13
Positive orthodomes	14	Negative pyramids *hkl*	26
Negative orthodomes	20		
Positive pyramids *hll*	16		134
Negative pyramids *hll*	15		

HABIT.

Crystals of terlinguaite possess three distinct habits:

1. Prismatic habit. In this habit the crystals are elongated in one direction, usually the *b* axis, similarly to the common habit of epidote. Crystal 1 (fig. 23) shows this habit well. More rarely, the elongation is in a pyramidal direction, such as shown by crystals 6 and 7 (figs. 26, 27, 28). No crystal has been observed where the elongation is parallel to the vertical axis.

2. Equidimensional habit. The crystals of this habit are thick and short and very rich in faces, many of which are of about the same size. Crystal 9 (fig. 30) is of this habit.

3. Tabular to *a* {100}. The large development of the orthopinacoid causes the crystals to assume a tabular shape, though the other forms present are never so small as to make the crystals thin tabular. Crystals 3 and 4 (figs. 24 and 25) approach this habit.

All of the three habits described above were noted by Moses. Some of the crystals have a thin tabular appearance due to the development of a large "contact face" where the terlinguaite rested on the calcite. This "contact face" may be so large as to give an altogether different shape to the crystal, although it has of course no crystallographical significance.

[a] Zambonini, F., Krystallographisches über den Epidot: Zeitschr. Kryst. Min., vol. 37, 1903, p. 21.

DESCRIPTION OF CRYSTALS.

Crystal 1 (fig. 23), the first crystal measured, is one which has a large number of forms, the crystal being extended in the direction of the *b* axis, with the zone of orthodomes somewhat striated parallel to their intersection. The crystal, not complete, is terminated at both ends, and has in addition a small cavity in the rear, the interior of which is profusely covered with faces. The drawing shown in figure 23 gives a general idea of the habit of the crystal, but shows only the largest faces. The exact relation of the small pyramids to the surrounding faces is difficult to decipher, on account of their small size. The rear of the crystal, not shown in the drawing, is very rich in faces. A total number of 106 faces were measured on this crystal,

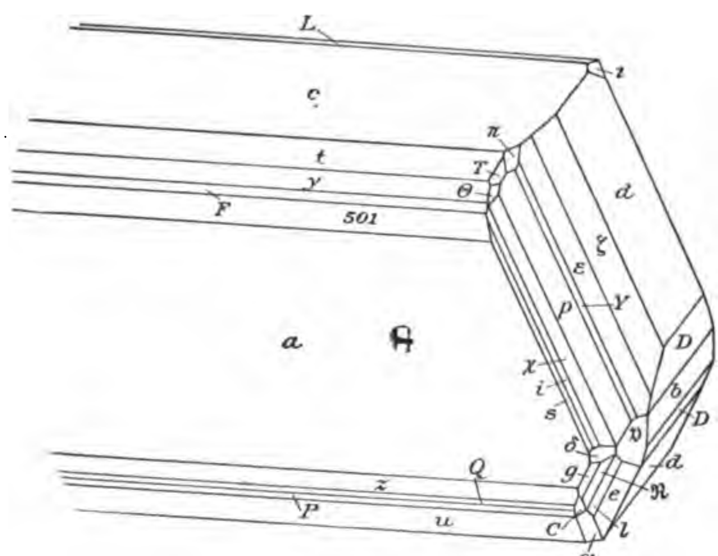


FIGURE 23.—Terlinguaite crystal 1: $c\{001\}$, $a\{100\}$, $b\{010\}$, $L\{\bar{1}04\}$, $t\{102\}$, $y\{101\}$, $F\{503\}$, $z\{\bar{3}01\}$, $Q\{\bar{3}02\}$, $P\{\bar{4}03\}$, $u\{\bar{1}01\}$, $d\{011\}$, $D\{031\}$, $\zeta\{144\}$, $\epsilon\{133\}$, $Y\{233\}$, $p\{111\}$, $\chi\{322\}$, $i\{211\}$, $s\{311\}$, $\delta\{210\}$, 𝔫$\{230\}$, $g\{\bar{2}11\}$, 𝔑$\{\bar{3}22\}$, $l\{\bar{4}33\}$, $e\{\bar{1}11\}$, $\pi\{112\}$, $T\{213\}$, $\theta\{212\}$, $C\{\bar{4}13\}$, $\alpha\{\bar{3}13\}$, $\iota\{\bar{1}24\}$.

but about 20 gave such poor reflections on account of their minute size or uneven surface that they could not definitely be determined. Four forms, all except the first one showing two faces, were noted only on this crystal. The forms are 𝔫$\{230\}$, $F\{503\}$, $U\{\bar{3}.1.11\}$, $\Delta\{131\}$. A few doubtful or vicinal forms also present on this crystal were described on page 109.

Crystal 3 (fig. 24) is a small incomplete crystal with a large striated face of $a\{100\}$ and a number of very small orthodomes, one of which, $M\{\bar{1}07\}$, is of especial interest, for, though a negative dome, it lies in front of the pole in the gnomonic projection, the angle $(\bar{1}07):(001)$ being less than β. The shape of this crystal is determined by the presence of a large "contact face," about in the position of $+\{3.4.12\}$,

which is in the rear of the crystal shown in figure 24. The broken space in the upper front part is occupied by irregularly bounded faces, some of which are parallel to those shown in the figure. The zone (111):(013) is a prominent one with a large face of {124}. Only one other form besides *M*{$\bar{1}$07}, namely *W*{632}, was observed on this crystal and on no other.

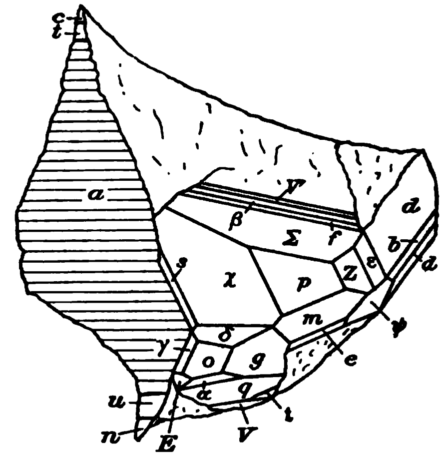


FIGURE 24.—Terlinguaite crystal 3: *u*{$\bar{1}$01}, *n*{$\bar{1}$02}, *f*{013}, *Z*{122}, *Σ*{124}, *β*{$\bar{1}$15}, *V*{$\bar{3}$19}, *r*{$\bar{4}$11}, *ψ*{$\bar{1}$22}, *E*{$\bar{5}$13}, *q*{$\bar{3}$15}, *t*{$\bar{2}$15}.

Crystal 4 (fig. 25), like the preceding one, is somewhat flattened parallel to the large *a* face. The clinodomes are present as large faces, but the clinopinacoid is entirely lacking. The zone (30$\bar{1}$) : (031) is well developed, large faces of (41$\bar{1}$) and (110) and a smaller face of (63$\bar{1}$) being present. The large face of (35$\bar{5}$) was strongly striated and gave two reflections, one of which agreed with (35$\bar{5}$) and the other with (12$\bar{2}$). On the other side of the crystal a long line face of the rare form **m** {$\bar{6}$35}, also noted on crystal 5, lies between ($\bar{4}$13) and ($\bar{1}$11). The prism **m** {520}, shown in figure 25, occurs only on this crystal.

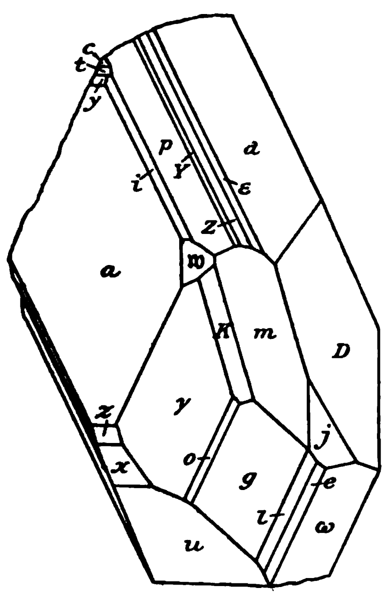


FIGURE 25.—Terlinguaite crystal 4: **m**{520}, *j*{120}, *z*{$\bar{3}$01}, *x*{$\bar{2}$01}, *ω*{$\bar{3}$55}, *K*{$\bar{6}$31}.

Crystal 6 (fig. 26) is the most interesting as well as the most complex of all those examined. The crystal originally measured 15 millimeters in length, but it was so firmly held on the specimen that on removal it cleaved into seven pieces, all of which were saved and measured. The central piece is the largest and is terminated at both ends by the cleavage faces of {$\bar{1}$01}. The remarkable feature of this crystal is that its prismatic shape is due to the development of the zone (103): (010), the three faces *b* {010}, *ε* {133}, *O* {113} being present as long faces with parallel intersections. Moreover, the orthodome zone is strongly striated and built up of alternating faces of (102) with (103) or (105), thus yielding a rounded dome surface

whose intersections with {113} are more or less parallel to the edges of the zone (103) : (010). The alternating faces of the orthodome zone make it difficult to represent the crystal in the drawing, therefore in figure 26 the intersection edges have been given an interme-

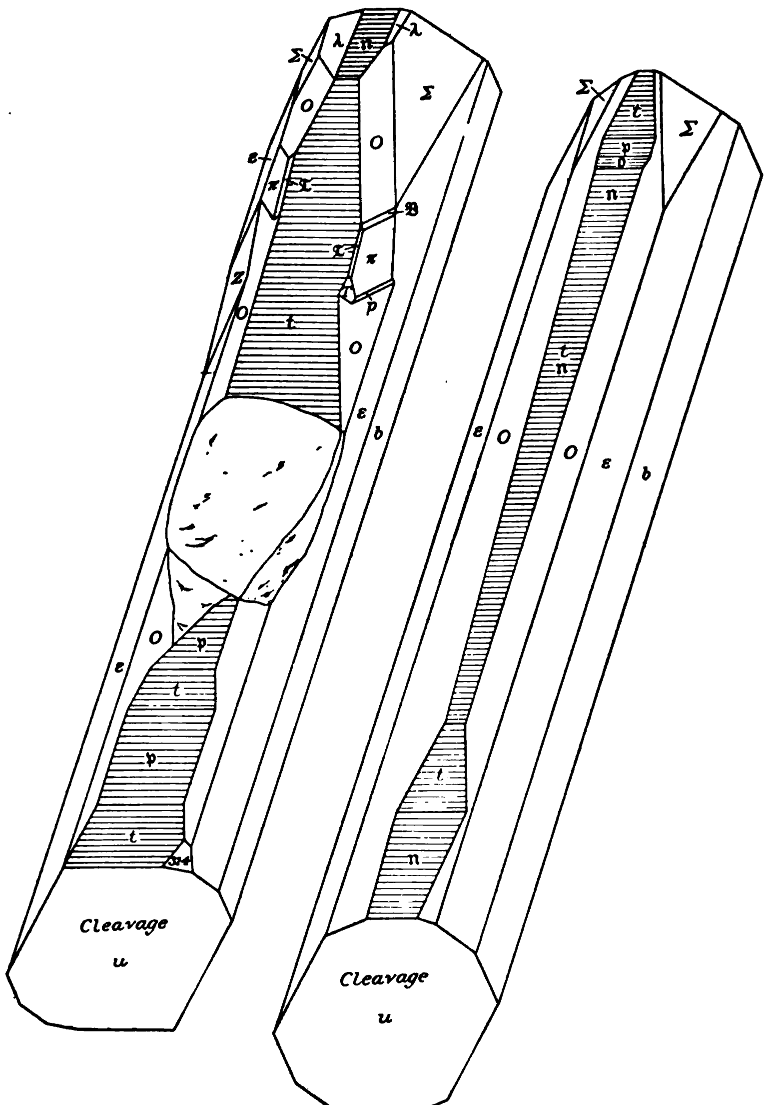


FIGURE 26.—Terlinguaite crystal 6: $\mathfrak{n}$ {105}, $\mathfrak{p}$ {103}, $\mathfrak{n}$ {104}, O {113}, $\mathfrak{B}$ {337}, $\mathfrak{T}$ {326}, T {213}, λ {115}, Z {122}, Σ {124}, ϵ {133}, t {102}.

diate position and drawn as straight lines. The faces of the form {124} in reality extend down almost the entire length of the crystal, appearing as small facets between {113} and {133}. In the drawings shown it was intended to give a general idea of the habit of the

crystal rather than an absolutely correct view, which, by reason of the frequent alternating occurrence of two or more forms, would be very difficult. The two views shown in figure 26 represent the two sides of the crystal. None of the other six parts of the crystal have been illustrated, as they do not show any particular features.

This crystal is particularly rich in small or minute faces, many of them mere line faces. A total of 16 forms were observed only on this crystal. These are $\mathfrak{f}$ {045}, $\mathfrak{g}$ {035}, $\mathfrak{h}$ {012}, $\mathfrak{a}$ {049}, $\mathfrak{b}$ {025}, $\mathfrak{n}$ {104}, *W* {301}, $\mathfrak{k}$ {12.0.1}, $\mathfrak{C}$ {$\bar{5}02$}, $\mathfrak{K}$ {344}, $\mathfrak{O}$ {411}, ω {$\bar{3}55$}, $\mathfrak{S}$ {$\bar{5}22$}, $\mathfrak{Y}$ {215}, Ξ {$\bar{3}34$}, *s* {3.4.14}.

Crystal 7 (figs. 27 and 28) is a small crystal very rich in faces, being incomplete only on one end. By the large development of certain pyramids and the occurrence of the orthodomes as very narrow vertical faces, the crystal has a peculiar cone-shaped appearance which is illustrated in figures 27 and 28, showing the front and back of this crystal. The upper termination on figure 27 is drawn larger than it is in reality, to better show the relations of the numerous forms occurring there. The zone ($30\bar{1}$):(031) is again well developed, except for ($30\bar{1}$), which is not present, and it is the presence of ($41\bar{1}$), ($63\bar{1}$), (110), and (031), all intersecting in parallel lines, which gives the crystal its curious appearance. The zone ($13\bar{1}$):(010) is also well developed, the large faces of {$\bar{1}31$} and {010} playing their share in the habit of the crystal. The faces (102) and (001) are, in reality, very minute, the upper end of the crystal appearing almost like a point, as is better shown in figure 28.

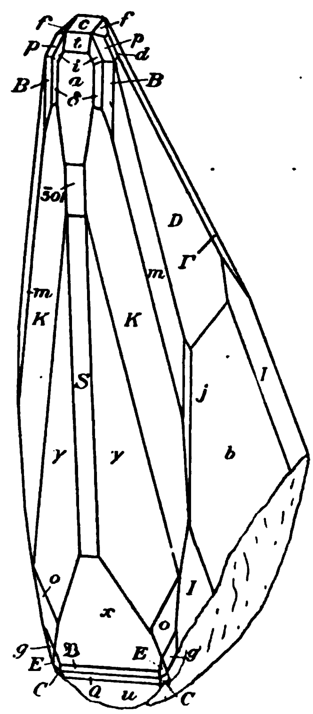


FIGURE 27.—Terlinguaite crystal 7 (front): *f* {013}, *D* {031}, *B* {320}, *x* {$\bar{2}01$}, *Q* {$\bar{3}02$}, *S* {$\bar{4}01$}, $\mathfrak{M}$ {$\bar{5}03$}, *I* {$\bar{1}31$}, *o* {$\bar{3}11$}, γ {$\bar{4}11$}, Γ {$\bar{3}44$}, *K* {$\bar{6}31$}, *E* {$\bar{5}13$}, *C* {$\bar{4}13$}.

While the side of the crystal shown in figure 27 is drawn in ideal proportion, the other side, figure 28, is shown as it really appears. A different combination is seen here, though the essential pyramids of the entire crystal are negative. The pyramid {$34\bar{4}$} has a large face on one side and {$4\bar{3}\bar{5}$} occurs with a large face on the other side. These two forms with ($03\bar{1}$) determine the habit on this side of the crystal, the zone ($13\bar{1}$):(010), better developed on this side, also materially influencing its shape.

The prism zone is rather well developed, the forms present, in the order of their size, being *b* {010}, *m* {110}, *a* {100}, *j* {120}, *B* {320}, and δ {210}. Altogether nineteen faces were measured in the prism

zone. Of the orthodomes, θ $\{\bar{5}01\}$, present only once and only on this crystal, lies between $(63\bar{1})$ and $(6\bar{3}\bar{1})$. S $\{\bar{4}01\}$ occurs as a long, narrow face between the two faces of $\{\bar{4}11\}$. x $\{\bar{2}01\}$ is the largest orthodome on the crystal. R $\{\bar{4}05\}$ and ŋ $\{\bar{3}04\}$ occur as long, narrow faces between $(43\bar{5})$ and $(4\bar{3}\bar{5})$ and $(32\bar{4})$ and $(3\bar{2}\bar{4})$, respectively. D $\{031\}$ is the only large clinodome on the crystal. To the brief description of the pyramids on this crystal, already given, need only be added the occurrence of $(51\bar{5})$ and $(31\bar{3})$, between $(11\bar{1})$ and $(10\bar{1})$, the latter being probably a true crystal face and not a cleavage surface. Four forms which were not found on any other crystal and of which but one face occurred are: $\theta\{\bar{5}01\}$, $R\{\bar{4}05\}$, ŋ $\{166\}$, $\mu\{\bar{6}32\}$, the last two being line faces.

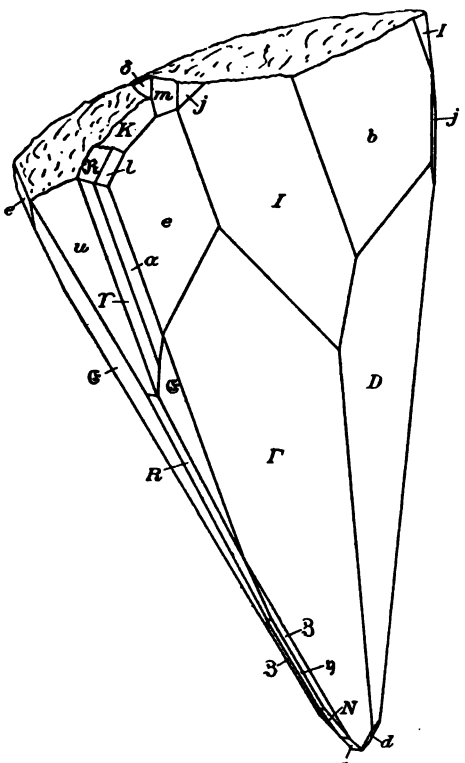


FIGURE 28.—Terlinguaite crystal 7 (back): δ $\{210\}$, x $\{\bar{3}05\}$, ŋ $\{\bar{3}04\}$, R $\{\bar{4}05\}$, N $\{\bar{2}03\}$, Γ $\{\bar{3}44\}$, Z $\{\bar{3}24\}$, E $\{\bar{4}35\}$, Υ $\{\bar{5}15\}$.

Crystal 8 (fig. 29), though incomplete, shows a rich combination. Many of the larger faces have an equal development, the resulting crystal approaching the equidimensional habit. The large orthodome η $\{901\}$ is rather unusual, otherwise the essential forms are such as frequently occur. The zones $(51\bar{3})$, $(41\bar{3})$, $(31\bar{3})$, $(21\bar{3})$, $(11\bar{3})$, $(01\bar{3})$; (013), $(\bar{1}15)$, $(\bar{2}17)$, etc.; (100), (011), $(\bar{1}00)$, $(0\bar{1}\bar{1})$ are all well developed. The only form observed on this crystal and on no other is η $\{901\}$.

Crystal 9 is shown in ideal representation in figure 30, except that the upper and lower faces of a form are not shown of the same size, but more as they actually appear. The left-hand side of the crystal is, however, drawn in ideal proportion to the right-hand half. The crystal belongs to and well represents the second or equidimensional habit, and also shows the richness of combination usual on crystals of this habit. The zonal relations of the various faces can be made out in the drawing, every face present lying in at least one well developed zone. Some of the more prominent zones seen on this crystal, with the faces belonging to them, are: The orthodome zone with (001), (105), (102), (203), (401), (100),

(20$\bar{1}$), (30$\bar{2}$), (60$\bar{5}$), (10$\bar{1}$), (30$\bar{4}$), (20$\bar{3}$), (30$\bar{5}$), (10$\bar{2}$); also, but not shown in the drawing, (20$\bar{1}$), (10$\bar{4}$), (12.0.$\bar{1}$); the prism zone with

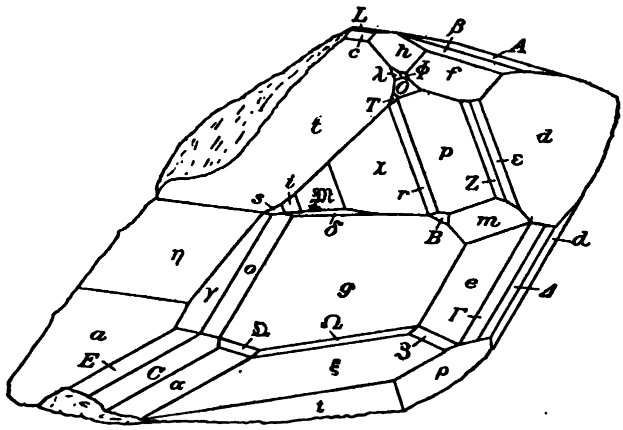


Figure 29.—Terlinguaite crystal 8: $L\,\{\bar{1}04\}$, $h\,\{015\}$, $\eta\,\{901\}$, $\delta\,\{210\}$, $B\,\{320\}$, $A\,\{\bar{2}17\}$, $r\,\{433\}$, $\chi\{322\}$, $\Delta\,\{\bar{2}33\}$, $E\,\{\bar{5}13\}$, $\Phi\,\{\bar{5}24\}$, $\xi\,\{\bar{2}13\}$, $\mathfrak{Z}\,\{\bar{3}24\}$, $\mathfrak{M}\,\{533\}$, $\Gamma\,\{\bar{3}44\}$, $g\,\{\bar{2}11\}$, $\gamma\,\{\bar{4}11\}$, $C\,\{\bar{4}13\}$, $\Omega\,\{\bar{2}12\}$, $\rho\,\{\bar{1}13\}$, $t\,\{\bar{2}15\}$.

(100), (830), (210), (320), (110), (120), (010); the clinodome zone, with (001), (017), (015), (013,) (011), (010) (note that the last

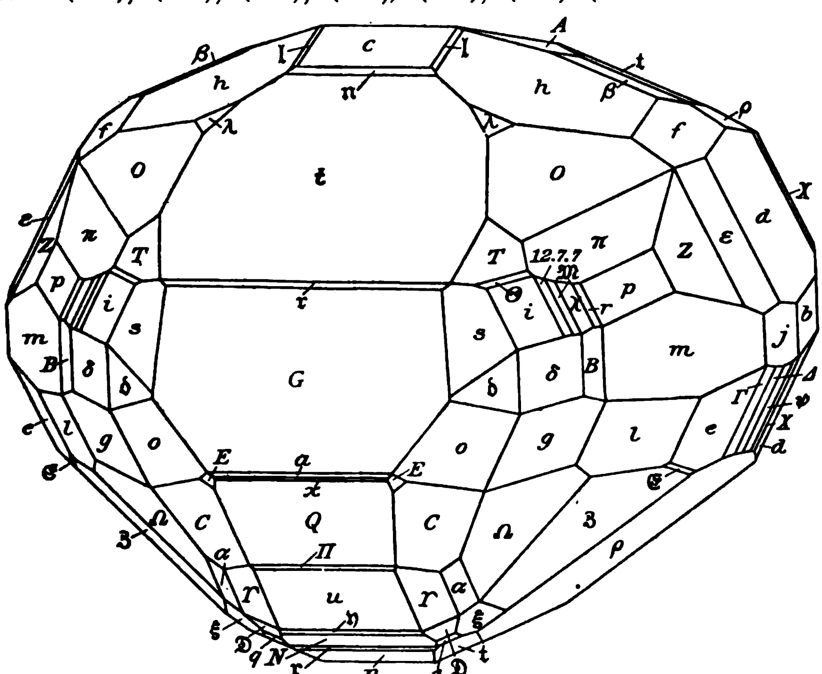


Figure 30.—Terlinguaite crystal 9: $\mathfrak{l}\,\{017\}$, $h\,\{015\}$, $f\,\{013\}$, $d\,\{011\}$, $\mathfrak{d}\,\{830\}$, $\delta\,\{210\}$, $B\,\{320\}$, $j\,\{120\}$, $\mathfrak{n}\,\{105\}$, $\mathfrak{r}\,\{203\}$, $t\,\{102\}$, $G\,\{401\}$, $z\,\{\bar{2}01\}$, $\Pi\,\{\bar{6}05\}$, $u\,\{\bar{1}01\}$, $\mathfrak{y}\,\{\bar{3}04\}$, $N\,\{\bar{2}03\}$, $\mathfrak{x}\,\{\bar{3}05\}$, $n\,\{\bar{1}02\}$, $s\,\{311\}$, $\lambda\,\{115\}$, $O\,\{113\}$, $p\,\{111\}$, $\pi\,\{112\}$, $\mathfrak{M}\,\{533\}$, $r\,\{433\}$, $Z\,\{122\}$, $\epsilon\{133\}$, $X\,\{\bar{1}33\}$, $g\,\{\bar{2}11\}$, $\Psi\,\{\bar{1}22\}$, $\Delta\,\{\bar{2}33\}$, $l\,\{\bar{4}33\}$, $\Gamma\,\{\bar{3}44\}$, $\mathfrak{E}\,\{\bar{4}35\}$, $\mathfrak{Z}\,\{\bar{3}24\}$, $E\,\{\bar{5}13\}$, $\Omega\,\{\bar{2}12\}$, $C\,\{\bar{4}13\}$, $\xi\,\{\bar{2}13\}$, $t\,\{\bar{2}15\}$, $a\,\{\bar{3}13\}$, $\beta\,\{\bar{1}15\}$, $\Upsilon\,\{\bar{5}15\}$, $\mathfrak{B}\,\{\bar{4}15\}$, $q\,\{\bar{3}15\}$, $\rho\,\{\bar{1}13\}$, $T\,\{2\bar{1}3\}$.

intercept decreases regularly by 2); the pyramid zones (positive and negative), (100), (311), (211), (12.7.7), (533), (322), (655), (111),

(122), (133), (011) and (100), $(31\bar{1})$, $(21\bar{1})$, $(43\bar{3})$, $(11\bar{1})$, $(34\bar{4})$, $(23\bar{3})$, $(12\bar{2})$, $(13\bar{3})$, $(01\bar{1})$, and several other forms not shown in the drawing. Further zones are (001), (115), (113), (112), (111), (110), $(11\bar{1})$, $(11\bar{3})$, $(00\bar{1})$; (213), (212), (211), (210), $(21\bar{1})$, $(21\bar{2})$, $(21\bar{3})$, $(21\bar{5})$. All of the positive forms shown in the drawing are included in one or more of the above zones. The negative pyramids are particularly well developed in zones, the forms shown in the figure falling in the zones (100), $(51\bar{3})$, $(41\bar{3})$, $(31\bar{3})$, $(21\bar{3})$, $(11\bar{3})$, $(01\bar{3})$; $(51\bar{5})$, $(41\bar{5})$, $(31\bar{5})$, $(21\bar{5})$, $(11\bar{5})$, $(01\bar{5})$; $(10\bar{2})$, $(31\bar{5})$, $(21\bar{3})$, $(32\bar{4})$, $(43\bar{5})$, $(11\bar{1})$. The zone (013), $(\bar{1}15)$, $(\bar{2}17)$, $(\bar{3}19)$, $(\bar{4}.1.11)$, $(\bar{1}02)$ is also well developed. The following forms were observed only on crystal 9: $\mathfrak{d}$ {830}, $\mathfrak{J}$ $\{\overline{12}.0.1\}$.

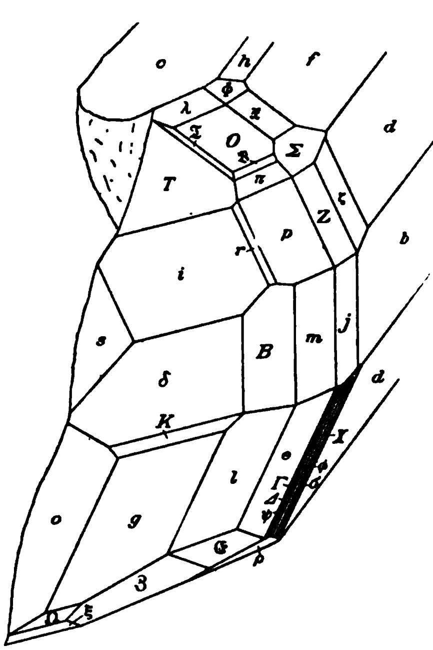


FIGURE 31.—Terlinguaite crystal 11: $o\{\bar{3}11\}$, $\zeta\{144\}$, $r\{433\}$, $K\{\bar{6}31\}$, $\sigma\{\bar{1}55\}$, $l\{\bar{4}33\}$, $\phi\{\bar{1}44\}$, $X\{\bar{1}33\}$, $\psi\{\bar{1}22\}$, $\Delta\{\bar{2}33\}$, $\Gamma\{\bar{3}44\}$, $\Omega\{\bar{2}12\}$, $\Xi\{\bar{4}35\}$, $\xi\{\bar{2}13\}$, $\mathfrak{Z}\{\bar{3}24\}$, $\rho\{\bar{1}13\}$.

On crystal 11 (fig. 31) the clinodomes are developed as large long faces, the base being present as the largest face on the crystal, thus giving it a rather unusual appearance. A part of the crystal is shown in figure 31, where the unusual features are the relatively large development of the positive pyramids, lying in the zones (120), Z (122), Σ (124), $\mathfrak{X}$ (126), Φ (128) (note that the last index increases regularly by 2); and T (213), $\mathfrak{T}$ (326), (113), (126), (013). The rather rare form $\mathfrak{H}$ {337} is also shown. The following forms were observed only on this crystal: $\mathfrak{j}$ {308}, $\mathfrak{r}$ {317}, $\mathfrak{n}$ $\{\bar{2}16\}$.

DIFFERENT ORIENTATIONS AND TRANSFORMATION SYMBOLS.

No orientation was found which was better than the one here adopted, namely, M_2. About the only drawback to it is that the cleavage form is not a pinacoid, such as {001}, but a rear dome $\{\bar{1}01\}$. After considerable study of the gnomonic projection, the writer decided that the two orientations here given, S_1 and S_2, were the best that could be formed after M_2. A glance at the list of forms on the following pages will show, however, that much of the

simplicity of the indices under M_2 is lost under S_1 and S_2. In the orientation S_1 the cleavage is made the base, the orthopinacoid being kept as such, but the angle β becomes very small (44° 04′). Under S_2 the cleavage again becomes the base, but the form {101} M_2 is now the orthopinacoid. While this affords a generally good orientation, the symbols of many of the forms become rather complex.

A good idea of the relative merits of the different orientations may be obtained from tho following table, showing the relative indices of some forms:

Indices of several forms for different orientations of terlinguaite.

M_1........	001	100	130	011	103	$\bar{1}03$	$\bar{2}03$	133	$\bar{1}33$
M_2........	001	100	110	011	101	$\bar{1}01$	$\bar{2}01$	111	$\bar{1}11$
S_1........	$\bar{1}01$	100	110	$\bar{1}11$	$\bar{2}01$	001	101	$\bar{2}11$	011
S_2........	$\bar{1}01$	101	111	$\bar{1}11$	100	001	103	110	012

Following are the elements for the different orientations:

Elements for different orientations of terlinguaite.

Orientation.	$a:b:c$.	β
		° ′
M_1......	.5338 : 1 : 2.0245	74 23
M_2......	1.6050 : 1 : 2.0245	74 23
S_1......	2.2169 : 1 : 2.0245	44 04
S_2......	1.1088 : 1 : 1.4499	76 12

Following are the transformation symbols:

$$p.q\,(M_1)=3\,p.q\,(M_2), \quad \text{or } h_1.k_1.l_1\,(M_2)=3\,h.k.l\,(M_1).$$
$$p.q\,(M_2)=-(p+1).q\,(S_1), \text{ or } h_2.k_2.l_2\,(S_1)=-(h_1+l_1).k_1.l_1\,(M_2).$$
$$p.q\,(M_2)=\frac{p+1}{p-1}.\frac{q}{p-1}(S_2), \quad \text{or } h_3.k_3.l_3.(S_2)=-(h_1+l_1).2k_1.-(h_1-l_1)\,(M_2).$$

The following table shows the indices of all the forms in the four different orientations given above. As can readily be seen, that of M_2 is much to be preferred.

Indices for different orientations of terlinguaite forms.

Letter.	Gdt. M_1.	Miller M_1.	Gdt. M_2.	Miller M_2.	Gdt. S_1.	Miller S_1.	Gdt. S_2.	Miller S_2.
c	0	001	0	001	-10	$\bar{1}01$	-10	$\bar{1}01$
b	0∞	010	0∞	010	0∞	010	0∞	010
a	$\infty 0$	100	$\infty 0$	100	$\infty 0$	100	$+10$	101
j	$\infty 6$	160	$\infty 2$	120	$\infty 2$	120	$+12$	121
𝔳	$\infty\frac{9}{2}$	290	$\infty\frac{3}{2}$	230	$\infty\frac{3}{2}$	230	$+1\frac{3}{2}$	232
m	$\infty 3$	130	∞	110	∞	110	$+1$	111
B	$\infty 2$	120	$\frac{3}{2}\infty$	320	$\frac{3}{2}\infty$	320	$+1\frac{2}{3}$	323
∂	$\infty\frac{3}{2}$	230	2∞	210	2∞	210	$+1\frac{1}{2}$	212
𝔪	$\infty\frac{6}{5}$	560	$\frac{5}{2}\infty$	520	$\frac{5}{2}\infty$	520	$+1\frac{2}{5}$	525
𝔡	$\infty\frac{9}{8}$	890	$\frac{8}{3}\infty$	830	$\frac{8}{3}\infty$	830	$+1\frac{3}{8}$	838
𝔢	2∞	210	6∞	610	6∞	610	$+1\frac{1}{6}$	616
D	03	031	03	031	-13	$\bar{1}31$	-13	$\bar{1}31$
d	01	011	01	011	-1	$\bar{1}11$	-1	$\bar{1}11$
𝔣	$0\frac{4}{5}$	045	$0\frac{4}{5}$	045	$-1\frac{4}{5}$	$\bar{5}45$	$-1\frac{4}{5}$	$\bar{5}45$
𝔤	$0\frac{3}{5}$	035	$0\frac{3}{5}$	035	$-1\frac{3}{5}$	$\bar{5}35$	$-1\frac{3}{5}$	$\bar{5}35$
𝔥	$0\frac{1}{2}$	012	$0\frac{1}{2}$	012	$-1\frac{1}{2}$	$\bar{2}12$	$-1\frac{1}{2}$	$\bar{2}12$
𝔞	$0\frac{4}{9}$	049	$0\frac{4}{9}$	049	$-1\frac{4}{9}$	$\bar{9}49$	$-1\frac{4}{9}$	$\bar{9}49$
𝔟	$0\frac{2}{5}$	025	$0\frac{2}{5}$	025	$-1\frac{2}{5}$	$\bar{5}25$	$-1\frac{2}{5}$	$\bar{5}25$
f	$0\frac{1}{3}$	013	$0\frac{1}{3}$	013	$-1\frac{1}{3}$	$\bar{3}13$	$-1\frac{1}{3}$	$\bar{3}13$
h	$0\frac{1}{5}$	015	$0\frac{1}{5}$	015	$-1\frac{1}{5}$	$\bar{5}15$	$-1\frac{1}{5}$	$\bar{5}15$
𝔩	$0\frac{1}{7}$	017	$0\frac{1}{7}$	017	$-1\frac{1}{7}$	$\bar{7}17$	$-1\frac{1}{7}$	$\bar{7}17$
𝔲	$+\frac{1}{15}0$	1. 0. 15	$+\frac{1}{5}0$	105	$-\frac{6}{5}0$	$\bar{6}05$	$-\frac{3}{2}0$	$\bar{3}02$
𝔫	$+\frac{1}{12}0$	1. 0. 12	$+\frac{1}{4}0$	104	$-\frac{5}{4}0$	$\bar{5}04$	$-\frac{5}{3}0$	$\bar{5}03$
𝔭	$+\frac{1}{9}0$	109	$+\frac{1}{3}0$	103	$-\frac{4}{3}0$	$\bar{4}03$	-20	$\bar{2}01$
𝔧	$+\frac{1}{8}0$	108	$+\frac{3}{8}0$	308	$-\frac{11}{8}0$	$\overline{11}.0.8$	$-\frac{11}{5}0$	$\overline{11}.0.5$
t	$+\frac{1}{6}0$	106	$+\frac{1}{2}0$	102	$-\frac{3}{2}0$	$\bar{3}02$	-30	$\bar{3}01$
𝔯	$+\frac{2}{9}0$	209	$+\frac{2}{3}0$	203	$-\frac{5}{3}0$	$\bar{5}03$	-50	$\bar{5}01$
𝔑	$+\frac{1}{4}0$	104	$+\frac{3}{4}0$	304	$-\frac{7}{4}0$	$\bar{7}04$	-70	$\bar{7}01$
y	$+\frac{1}{3}0$	103	$+10$	101	-20	$\bar{2}01$	$\infty 0$	100
𝔰	$+\frac{4}{9}0$	409	$+\frac{4}{3}0$	403	$-\frac{7}{3}0$	$\bar{7}03$	$+70$	701
F	$+\frac{5}{9}0$	509	$+\frac{5}{3}0$	503	$-\frac{8}{3}0$	$\bar{8}03$	$+40$	401
w	$+10$	101	$+30$	301	-40	$\bar{4}01$	$+20$	201
G	$+\frac{4}{3}0$	403	$+40$	401	-50	$\bar{5}01$	$+\frac{5}{3}0$	503
η	$+30$	301	$+90$	901	-10.0	$\overline{10}.0.1$	$+\frac{5}{4}0$	504
𝔨	$+40$	401	$+12.0$	12. 0. 1	-13.0	$\overline{13}.0.1$	$+\frac{13}{11}0$	13. 0. 11
M	$-\frac{1}{21}0$	$\bar{1}.0.21$	$-\frac{1}{7}0$	$\bar{1}07$	$-\frac{6}{7}0$	$\bar{6}07$	$-\frac{3}{4}0$	$\bar{3}04$
L	$-\frac{1}{12}0$	$\bar{1}.0.12$	$-\frac{1}{4}0$	$\bar{1}04$	$-\frac{3}{4}0$	$\bar{3}04$	$-\frac{3}{5}0$	$\bar{3}05$
𝔐	$-\frac{1}{9}0$	$\bar{1}09$	$-\frac{1}{3}0$	$\bar{1}03$	$-\frac{2}{3}0$	$\bar{2}03$	$-\frac{1}{2}0$	$\bar{1}02$
n	$-\frac{1}{6}0$	$\bar{1}06$	$-\frac{1}{2}0$	$\bar{1}02$	$-\frac{1}{2}0$	$\bar{1}02$	$-\frac{1}{3}0$	$\bar{1}03$
𝔵	$-\frac{1}{5}0$	$\bar{1}05$	$-\frac{3}{5}0$	$\bar{3}05$	$-\frac{2}{5}0$	$\bar{2}05$	$-\frac{1}{4}0$	$\bar{1}04$
N	$-\frac{2}{9}0$	$\bar{2}09$	$-\frac{2}{3}0$	$\bar{2}03$	$-\frac{1}{3}0$	$\bar{1}03$	$-\frac{1}{5}0$	$\bar{1}05$
𝔜	$-\frac{1}{4}0$	$\bar{1}04$	$-\frac{3}{4}0$	$\bar{3}04$	$-\frac{1}{4}0$	$\bar{1}04$	$-\frac{1}{7}0$	$\bar{1}07$
R	$-\frac{4}{15}0$	$\bar{4}.0.15$	$-\frac{4}{5}0$	$\bar{4}05$	$-\frac{1}{5}0$	$\bar{1}05$	$-\frac{1}{9}0$	$\bar{1}09$
u	$-\frac{1}{3}0$	$\bar{1}03$	-10	$\bar{1}01$	0	001	0	001
Π	$-\frac{2}{5}0$	$\bar{2}05$	$-\frac{6}{5}0$	$\bar{6}05$	$+\frac{1}{5}0$	105	$+\frac{1}{11}0$	1. 0. 11
P	$-\frac{4}{9}0$	$\bar{4}09$	$-\frac{4}{3}0$	$\bar{4}03$	$+\frac{1}{3}0$	103	$+\frac{1}{7}0$	107
Q	$-\frac{1}{2}0$	$\bar{1}02$	$-\frac{3}{2}0$	$\bar{3}02$	$+\frac{1}{2}0$	102	$+\frac{1}{5}0$	105
𝔅	$-\frac{5}{9}0$	$\bar{5}09$	$-\frac{5}{3}0$	$\bar{5}03$	$+\frac{2}{3}0$	203	$+\frac{1}{4}0$	104
x	$-\frac{2}{3}0$	$\bar{2}03$	-20	$\bar{2}01$	$+10$	101	$+\frac{1}{3}0$	103
ℭ	$-\frac{5}{6}0$	$\bar{5}06$	$-\frac{5}{2}0$	$\bar{5}02$	$+\frac{3}{2}0$	302	$+\frac{3}{7}0$	307

Indices for different orientations of terlinguaite forms—Continued.

Letter.	Gdt. M_1.	Miller M_1.	Gdt. M_2.	Miller M_2.	Gdt. S_1.	Miller S_1.	Gdt. S_2.	Miller S_2.
z	-10	$\bar{1}01$	-30	$\bar{3}01$	$+20$	201	$+\frac{1}{2}0$	102
S	$-\frac{4}{3}0$	$\bar{4}03$	-40	$\bar{4}01$	$+30$	301	$+\frac{3}{5}0$	305
θ	$-\frac{5}{3}0$	$\bar{5}03$	-50	$\bar{5}01$	$+40$	401	$+\frac{2}{3}0$	203
𝔵	$-\frac{7}{3}0$	$\bar{7}03$	-70	$\bar{7}01$	$+60$	601	$+\frac{3}{4}0$	304
𝔍	-40	$\bar{4}01$	-12.0	$\overline{12}.0.1$	$+11.0$	$11.0.1$	$+\frac{11}{13}0$	$11.0.13$
r	$+\frac{1}{7}$	117	$+\frac{3}{7}\frac{1}{7}$	317	$-\frac{10}{7}\frac{1}{7}$	$10.1.7$	$-\frac{5}{2}\frac{1}{4}$	$\overline{10}.1.4$
s	$+1$	111	$+31$	311	-41	$\bar{4}11$	$+2\frac{1}{2}$	412
U	$-\frac{1}{11}$	$\bar{1}.1.11$	$-\frac{3}{11}\frac{1}{11}$	$\bar{3}.1.11$	$-\frac{8}{11}\frac{1}{11}$	$\bar{8}.1.11$	$-\frac{4}{7}\frac{1}{14}$	$\bar{8}.1.14$
V	$-\frac{1}{9}$	$\bar{1}19$	$-\frac{1}{3}\frac{1}{9}$	$\bar{3}19$	$-\frac{2}{3}\frac{1}{9}$	$\bar{6}19$	$-\frac{1}{2}\frac{1}{12}$	$\bar{6}.1.12$
q	$-\frac{1}{5}$	$\bar{1}15$	$-\frac{3}{5}\frac{1}{5}$	$\bar{3}15$	$-\frac{2}{5}\frac{1}{5}$	$\bar{2}15$	$-\frac{1}{4}\frac{1}{8}$	$\bar{2}18$
a	$-\frac{1}{3}$	$\bar{1}13$	$-1\frac{1}{3}$	$\bar{3}13$	$0\frac{1}{3}$	013	$0\frac{1}{6}$	016
o	-1	$\bar{1}11$	-31	$\bar{3}11$	$+21$	211	$+\frac{1}{2}\frac{1}{4}$	214
𝔊	$+\frac{1}{30}1$	$1.30.30$	$+\frac{1}{10}1$	$1.10.10$	$-\frac{11}{10}1$	$\overline{11}.10.10$	$-\frac{11}{9}\frac{10}{9}$	$\overline{11}.10.9$
τ	$+\frac{1}{24}1$	$1.24.24$	$+\frac{1}{8}1$	188	$-\frac{9}{8}1$	$\bar{9}88$	$-\frac{9}{7}\frac{8}{7}$	$\bar{9}87$
𝔑	$+\frac{1}{18}1$	$1.18.18$	$+\frac{1}{6}1$	166	$-\frac{7}{6}1$	$\bar{7}66$	$-\frac{7}{5}\frac{6}{5}$	$\bar{7}65$
𝔮	$+\frac{1}{15}1$	$1.15.15$	$+\frac{1}{5}1$	155	$-\frac{6}{5}1$	$\bar{6}55$	$-\frac{3}{2}\frac{5}{4}$	$\bar{6}54$
ζ	$+\frac{1}{12}1$	$1.12.12$	$+\frac{1}{4}1$	144	$-\frac{5}{4}1$	$\bar{5}44$	$-\frac{5}{3}\frac{4}{3}$	$\bar{5}43$
ε	$+\frac{1}{9}1$	199	$+\frac{1}{3}1$	133	$-\frac{4}{3}1$	$\bar{4}33$	$-2\frac{3}{2}$	$\bar{4}32$
Z	$+\frac{1}{6}1$	166	$+\frac{1}{2}1$	122	$-\frac{3}{2}1$	$\bar{3}22$	-32	$\bar{3}21$
v	$+\frac{1}{5}1$	155	$+\frac{3}{5}1$	355	$-\frac{8}{5}1$	$\bar{8}55$	$-4\frac{5}{2}$	$\bar{8}52$
Y	$+\frac{2}{9}1$	299	$+\frac{2}{3}1$	233	$-\frac{5}{3}1$	$\bar{5}33$	-53	$\bar{5}31$
𝔎	$+\frac{1}{4}1$	144	$+\frac{3}{4}1$	344	$-\frac{7}{4}1$	$\bar{7}44$	-74	$\bar{7}41$
p	$+\frac{1}{3}1$	133	$+1$	111	-21	$\bar{2}11$	∞	110
r	$+\frac{4}{9}1$	499	$+\frac{4}{3}1$	433	$-\frac{7}{3}1$	$\bar{7}33$	$+73$	731
χ	$+\frac{1}{2}1$	122	$+\frac{3}{2}1$	322	$-\frac{5}{2}1$	$\bar{5}22$	$+52$	521
𝔐	$+\frac{5}{9}1$	599	$+\frac{5}{3}1$	533	$-\frac{8}{3}1$	$\bar{8}33$	$+4\frac{3}{2}$	832
i	$+\frac{2}{3}1$	233	$+21$	211	-31	$\bar{3}11$	$+31$	311
𝔒	$+\frac{4}{3}1$	433	$+41$	411	-51	$\bar{5}11$	$+\frac{5}{3}\frac{1}{3}$	513
σ	$-\frac{1}{15}1$	$\bar{1}.15.15$	$-\frac{1}{5}1$	$\bar{1}55$	$-\frac{4}{5}1$	$\bar{4}55$	$-\frac{2}{3}\frac{5}{6}$	$\bar{4}56$
φ	$-\frac{1}{12}1$	$\bar{1}.12.12$	$-\frac{1}{4}1$	$\bar{1}44$	$-\frac{3}{4}1$	$\bar{3}44$	$-\frac{3}{5}\frac{4}{5}$	$\bar{3}45$
X	$-\frac{1}{9}1$	$\bar{1}99$	$-\frac{1}{3}1$	$\bar{1}33$	$-\frac{2}{3}1$	$\bar{2}33$	$-\frac{1}{2}\frac{3}{4}$	$\bar{2}34$
𝔏	$-\frac{2}{15}1$	$\bar{2}.15.15$	$-\frac{2}{5}1$	$\bar{2}55$	$-\frac{3}{5}1$	$\bar{3}55$	$-\frac{3}{7}\frac{5}{7}$	$\bar{3}57$
ψ	$-\frac{1}{6}1$	$\bar{1}66$	$-\frac{1}{2}1$	$\bar{1}22$	$-\frac{1}{2}1$	$\bar{1}22$	$-\frac{1}{3}\frac{2}{3}$	$\bar{1}23$
ω	$-\frac{1}{5}1$	$\bar{1}55$	$-\frac{3}{5}1$	$\bar{3}55$	$-\frac{2}{5}1$	$\bar{2}55$	$-\frac{1}{4}\frac{5}{8}$	$\bar{2}58$
Δ	$-\frac{2}{9}1$	$\bar{2}99$	$-\frac{2}{3}1$	$\bar{2}33$	$-\frac{1}{3}1$	$\bar{1}33$	$-\frac{1}{5}\frac{3}{5}$	$\bar{1}35$
Γ	$-\frac{1}{4}1$	$\bar{1}44$	$-\frac{3}{4}1$	$\bar{3}44$	$-\frac{1}{4}1$	$\bar{1}44$	$-\frac{1}{7}\frac{4}{7}$	$\bar{1}47$
𝔍	$-\frac{2}{7}1$	$\bar{2}77$	$-\frac{6}{7}1$	$\bar{6}77$	$-\frac{1}{7}1$	$\bar{1}77$	$-\frac{1}{13}\frac{7}{13}$	$\bar{1}.7.13$
e	$-\frac{1}{3}1$	$\bar{1}33$	-1	$\bar{1}11$	01	011	$0\frac{1}{2}$	012
l	$-\frac{4}{9}1$	$\bar{4}99$	$-\frac{4}{3}1$	$\bar{4}33$	$+\frac{1}{3}1$	133	$+\frac{1}{7}\frac{3}{7}$	137
𝔐	$-\frac{1}{2}1$	$\bar{1}22$	$-\frac{3}{2}1$	$\bar{3}22$	$+\frac{1}{2}1$	122	$+\frac{1}{5}\frac{2}{5}$	125
g	$-\frac{2}{3}1$	$\bar{2}33$	-21	$\bar{2}11$	$+1$	211	$+\frac{1}{3}$	113
𝔖	$-\frac{5}{6}1$	$\bar{5}66$	$-\frac{5}{2}1$	$\bar{5}22$	$+\frac{3}{2}1$	322	$+\frac{3}{7}\frac{2}{7}$	327
γ	$-\frac{4}{3}1$	$\bar{4}33$	-41	$\bar{4}11$	$+31$	311	$+\frac{3}{5}\frac{1}{5}$	315
𝔗	$+\frac{1}{6}\frac{1}{3}$	126	$+\frac{1}{2}\frac{1}{3}$	326	$-\frac{3}{2}\frac{1}{3}$	926	$-3\frac{2}{3}$	$\bar{9}23$
𝔓	$+\frac{1}{8}\frac{1}{4}$	128	$+\frac{3}{8}\frac{1}{4}$	328	$-\frac{11}{8}\frac{1}{4}$	$\overline{11}.2.8$	$-\frac{11}{5}\frac{2}{5}$	$\overline{11}.2.5$
k	$+\frac{1}{4}\frac{3}{4}$	134	$+\frac{3}{4}$	334	$-\frac{7}{4}\frac{3}{4}$	$\bar{7}34$	-73	$\bar{7}31$
π	$+\frac{1}{6}\frac{1}{2}$	136	$+\frac{1}{2}$	112	$-\frac{3}{2}\frac{1}{2}$	$\bar{3}12$	-31	$\bar{3}11$
𝔅	$+\frac{1}{7}\frac{3}{7}$	137	$+\frac{3}{7}$	337	$-\frac{10}{7}\frac{3}{7}$	$\overline{10}.3.7$	$-\frac{5}{2}\frac{3}{4}$	$\overline{10}.3.4$
O	$+\frac{1}{9}\frac{1}{3}$	139	$+\frac{1}{3}$	113	$-\frac{4}{3}\frac{1}{3}$	$\bar{4}13$	$-2\frac{1}{2}$	$\bar{4}12$
λ	$+\frac{1}{15}\frac{1}{5}$	$1.3.15$	$+\frac{1}{5}$	115	$-\frac{6}{5}\frac{1}{5}$	$\bar{6}15$	$-\frac{3}{2}\frac{3}{4}$	$\bar{6}34$

Indices for different orientations of terlinguaite forms—Continued.

Letter.	Gdt. M_1.	Miller M_1.	Gdt. M_2.	Miller M_2.	Gdt. S_1.	Miller S_1.	Gdt. S_2.	Miller S_2.
s	$+\frac{1}{14}\frac{2}{7}$	1.4.14	$+\frac{3}{14}\frac{2}{7}$	3.4.14	$-\frac{17}{14}\frac{2}{7}$	$\overline{17}.4.14$	$-\frac{17}{11}\frac{4}{11}$	$\overline{17}.4.11$
Σ	$+\frac{1}{12}\frac{1}{2}$	1.6.12	$+\frac{1}{4}\frac{1}{2}$	124	$-\frac{5}{4}\frac{1}{2}$	$\bar{5}24$	$-\frac{5}{3}\frac{2}{3}$	$\bar{5}23$
$\mathfrak{X}$	$+\frac{1}{18}\frac{1}{3}$	1.6.18	$+\frac{1}{6}\frac{1}{3}$	126	$-\frac{7}{6}\frac{1}{3}$	$\bar{7}26$	$-\frac{7}{5}\frac{1}{5}$	$\bar{7}15$
Φ	$+\frac{1}{24}\frac{1}{4}$	1.6.24	$+\frac{1}{8}\frac{1}{4}$	128	$-\frac{9}{8}\frac{1}{4}$	$\bar{9}28$	$-\frac{9}{7}\frac{2}{7}$	$\bar{9}27$
Λ	$+\frac{1}{3}3$	193	+13	131	−23	$\bar{2}31$	$\infty\frac{3}{2}$	230
W	$+2\frac{3}{2}$	232	$+3\frac{3}{2}$	632	$-4\frac{3}{2}$	$\bar{8}32$	$+2\frac{3}{4}$	834
θ	$+\frac{1}{3}\frac{1}{2}$	236	$+1\frac{1}{2}$	212	$-2\frac{1}{2}$	$\bar{4}12$	4∞	410
T	$+\frac{2}{9}\frac{1}{3}$	239	$+\frac{2}{3}\frac{1}{3}$	213	$-\frac{5}{3}\frac{1}{3}$	$\bar{5}13$	−51	$\bar{5}11$
Y	$+\frac{2}{15}\frac{1}{5}$	2.3.15	$+\frac{2}{5}\frac{1}{5}$	215	$-\frac{7}{5}\frac{1}{5}$	$\bar{7}15$	$-\frac{7}{3}\frac{1}{3}$	$\bar{7}13$
$\mathfrak{Z}$	$-\frac{1}{4}\frac{1}{2}$	$\bar{1}24$	$-\frac{3}{4}\frac{1}{2}$	$\bar{3}24$	$-\frac{1}{4}\frac{1}{2}$	$\bar{1}24$	$-\frac{1}{7}\frac{2}{7}$	$\bar{1}27$
Ξ	$-\frac{1}{4}\frac{3}{4}$	$\bar{1}34$	$-\frac{3}{4}$	$\bar{3}34$	$-\frac{1}{4}\frac{3}{4}$	$\bar{1}34$	$-\frac{1}{7}\frac{3}{7}$	$\bar{1}37$
ρ	$-\frac{1}{9}\frac{1}{3}$	$\bar{1}39$	$-\frac{1}{3}$	$\bar{1}13$	$-\frac{2}{3}\frac{1}{3}$	$\bar{2}13$	$-\frac{1}{2}\frac{1}{4}$	$\bar{2}14$
H	$-\frac{1}{12}\frac{1}{4}$	$\bar{1}.3.12$	$-\frac{1}{4}$	$\bar{1}14$	$-\frac{3}{4}\frac{1}{4}$	$\bar{3}14$	$-\frac{3}{5}\frac{1}{5}$	$\bar{3}15$
β	$-\frac{1}{15}\frac{1}{5}$	$\bar{1}.3.15$	$-\frac{1}{5}$	$\bar{1}15$	$-\frac{4}{5}\frac{1}{5}$	$\bar{4}15$	$-\frac{2}{3}\frac{1}{6}$	$\bar{4}16$
ι	$-\frac{1}{12}\frac{1}{2}$	$\bar{1}.6.12$	$-\frac{1}{4}\frac{1}{2}$	$\bar{1}24$	$-\frac{3}{4}\frac{1}{2}$	$\bar{3}24$	$-\frac{3}{5}\frac{2}{5}$	$\bar{3}25$
I	$-\frac{1}{3}3$	$\bar{1}93$	−13	$\bar{1}31$	03	031	$0\frac{3}{2}$	032
J	$-\frac{2}{15}\frac{1}{15}$	$\bar{2}.1.15$	$-\frac{2}{5}\frac{1}{15}$	$\bar{6}.1.15$	$-\frac{3}{5}\frac{1}{15}$	$\bar{9}.1.15$	$-\frac{3}{7}\frac{1}{21}$	$\bar{9}.1.21$
K	−23	$\bar{2}31$	−63	$\bar{6}31$	+53	531	$+\frac{5}{7}\frac{3}{7}$	537
μ	$-1\frac{3}{2}$	$\bar{2}32$	$-3\frac{3}{2}$	$\bar{6}32$	$+2\frac{3}{2}$	432	$+\frac{1}{2}\frac{3}{8}$	438
$\mathfrak{m}$	$-\frac{2}{5}\frac{3}{5}$	$\bar{2}35$	$-\frac{6}{5}\frac{3}{5}$	$\bar{6}35$	$+\frac{1}{5}\frac{3}{5}$	135	$+\frac{1}{11}\frac{3}{11}$	1.3.11
Ω	$-\frac{1}{3}\frac{1}{2}$	$\bar{2}36$	$-1\frac{1}{2}$	$\bar{2}12$	$0\frac{1}{2}$	012	$0\frac{1}{4}$	014
ξ	$-\frac{2}{9}\frac{1}{3}$	$\bar{2}39$	$-\frac{2}{3}\frac{1}{3}$	$\bar{2}13$	$-\frac{1}{3}$	$\bar{1}13$	$-\frac{1}{5}$	$\bar{1}15$
$\mathfrak{t}$	$-\frac{2}{15}\frac{1}{5}$	$\bar{2}.3.15$	$-\frac{2}{5}\frac{1}{5}$	$\bar{2}15$	$-\frac{3}{5}\frac{1}{5}$	$\bar{3}15$	$-\frac{3}{7}\frac{1}{7}$	$\bar{3}17$
$\mathfrak{n}$	$-\frac{1}{9}\frac{1}{6}$	$\bar{2}.3.18$	$-\frac{1}{3}\frac{1}{6}$	$\bar{2}16$	$-\frac{2}{3}\frac{1}{6}$	$\bar{4}16$	$-\frac{1}{2}\frac{1}{8}$	$\bar{4}18$
A	$-\frac{2}{21}\frac{1}{7}$	$\bar{2}.3.21$	$-\frac{2}{7}\frac{1}{7}$	$\bar{2}17$	$-\frac{5}{7}\frac{1}{7}$	$\bar{5}17$	$-\frac{5}{9}\frac{1}{9}$	$\bar{5}19$
C	$-\frac{4}{9}\frac{1}{3}$	$\bar{4}.3.9$	$-\frac{4}{3}\frac{1}{3}$	$\bar{4}13$	$+\frac{1}{3}$	113	$+\frac{1}{7}$	117
$\mathfrak{B}$	$-\frac{4}{15}\frac{1}{5}$	$\bar{4}.3.15$	$-\frac{4}{5}\frac{1}{5}$	$\bar{4}15$	$-\frac{1}{5}$	$\bar{1}15$	$-\frac{1}{9}$	$\bar{1}19$
$\mathfrak{A}$	$-\frac{4}{33}\frac{1}{11}$	$\bar{4}.3.33$	$-\frac{4}{11}\frac{1}{11}$	$\bar{4}.1.11$	$-\frac{7}{11}\frac{1}{11}$	$\bar{7}.1.11$	$-\frac{7}{15}\frac{1}{15}$	$\bar{7}.1.15$
$\mathfrak{E}$	$-\frac{4}{15}\frac{3}{5}$	$\bar{4}.9.15$	$-\frac{4}{5}\frac{3}{5}$	$\bar{4}35$	$-\frac{1}{5}\frac{3}{5}$	$\bar{1}35$	$-\frac{1}{9}\frac{1}{3}$	$\bar{1}39$
E	$-\frac{5}{9}\frac{1}{3}$	$\bar{5}39$	$-\frac{5}{3}\frac{1}{3}$	$\bar{5}13$	$+\frac{2}{3}\frac{1}{3}$	213	$+\frac{1}{4}\frac{1}{8}$	218
Γ	$-\frac{1}{3}\frac{1}{5}$	$\bar{5}.3.15$	$-1\frac{1}{5}$	$\bar{5}15$	$0\frac{1}{5}$	015	$0\frac{1}{10}$	0.1.10
$\mathfrak{M}$	$-\frac{5}{27}\frac{1}{9}$	$\bar{5}.3.27$	$-\frac{5}{9}\frac{1}{9}$	$\bar{5}19$	$-\frac{4}{9}\frac{1}{9}$	$\bar{4}19$	$-\frac{2}{7}\frac{1}{14}$	$\bar{4}.1.14$
$\mathfrak{Q}$	$-\frac{5}{12}\frac{1}{2}$	$\bar{5}.6.12$	$-\frac{5}{4}\frac{1}{2}$	$\bar{5}24$	$+\frac{1}{4}\frac{1}{2}$	124	$+\frac{1}{9}\frac{1}{18}$	2.1.18
$\mathfrak{N}$	$-\frac{2}{3}\frac{1}{4}$	$\bar{8}.3.12$	$-2\frac{1}{4}$	$\bar{8}14$	$+1\frac{1}{4}$	414	$+\frac{1}{3}\frac{1}{12}$	4.1.12

COORDINATE ANGLES ARRANGED IN ORDER OF INCREASING ϕ VALUE.

The following table is arranged in the order of increasing values of the ϕ angle to enable one more easily to find a given form of terlinguaite from the measurements. These angles are given for the normal position, the plane perpendicular to the prisms being polar and the clinopinacoid being the first meridian. In a table following this one (p. 140) the angular values are given for the clinopinacoid as pole, the orthodome zone being used as the prism zone.

Forms of terlinguaite arranged in order of increasing ϕ value.

No.	Letter.	Symbol M_2.		ϕ	ρ
		Gdt.	Miller.		
				° ′	° ′
1	b	0∞	010	0 00	90 00
2	σ	$-\frac{1}{5}1$	$\bar{1}55$	0 29	63 43
3	ϕ	$-\frac{1}{4}1$	$\bar{1}44$	1 22	63 43
4	β	$-\frac{1}{5}$	$\bar{1}15$	2 25	22 04
5	D	03	031	2 38	80 40
6	ι	$-\frac{1}{4}\frac{1}{2}$	$\bar{1}24$	2 45	45 23
7	X	$-\frac{1}{3}1$	$\bar{1}33$	4 28	63 47
8	H	$-\frac{1}{4}$	$\bar{1}14$	5 29	26 57
9	L	$-\frac{2}{5}1$	$\bar{2}55$	6 55	63 53
10	d	01	011	7 52	63 56
11	I	-13	$\bar{1}31$	9 39	80 47
12	$\mathfrak{f}$	$0\frac{4}{5}$	045	9 48	58 41
13	Υ	$-\frac{1}{2}1$	$\bar{1}22$	10 33	64 06
14	$\mathfrak{G}$	$+\frac{1}{10}1$	1. 10. 10	11 28	64 10
15	τ	$+\frac{1}{8}1$	188	12 25	64 15
16	$\mathfrak{g}$	$0\frac{3}{5}$	035	12 58	51 16
17	$\mathfrak{p}$	$+\frac{1}{6}1$	166	13 10	64 23
18	ρ	$-\frac{1}{3}$	$\bar{1}13$	13 11	34 44
19	ω	$-\frac{3}{5}1$	$\bar{3}55$	14 05	64 24
20	Λ	$+13$	131	14 41	80 57
21	$\mathfrak{q}$	$+\frac{1}{5}1$	155	15 00	64 30
22	$\mathfrak{h}$	$0\frac{1}{2}$	012	15 26	46 24
23	Δ	$-\frac{2}{3}1$	$\bar{2}33$	16 23	64 39
24	ζ	$+\frac{1}{4}1$	144	16 43	64 41
25	$\mathfrak{a}$	$0\frac{4}{9}$	049	17 15	43 18
26	j	$\infty 2$	120	17 58	90 00
27	A	$-\frac{2}{7}\frac{1}{7}$	$\bar{2}17$	18 16	16 56
28	$\mathfrak{b}$	$0\frac{2}{5}$	025	19 03	40 35
29	Γ	$-\frac{3}{4}1$	$\bar{3}44$	19 12	65 00
30	ϵ	$+\frac{1}{3}1$	133	19 30	65 02
31	f	$0\frac{1}{3}$	013	22 30	36 09
32	I	$+\frac{6}{7}1$	677	22 40	65 30
33	U	$-\frac{3}{11}\frac{1}{11}$	$\bar{3}$. 1. 11	23 05	11 19
34	$\mathfrak{u}$	$\infty\frac{3}{2}$	230	23 23	90 00
35	Z	$+\frac{1}{2}1$	122	24 49	65 51

Forms of terlinguaite arranged in order of increasing ϕ value—Continued.

No.	Letter.	Symbol M_2. Gdt.	Symbol M_2. Miller.	ϕ	ρ
				° ′	° ′
36	Ξ	$-\frac{3}{4}$	$\bar{3}34$	24 54	59 09
37	$\mathfrak{u}$	$-\frac{1}{3}\frac{1}{6}$	$\bar{2}16$	25 05	20 26
38	e	-1	$\bar{1}11$	27 02	66 15
39	v	$+\frac{3}{5}1$	355	27 48	66 24
40	Y	$+\frac{2}{3}1$	233	29 42	66 47
41	Σ	$+\frac{1}{4}\frac{1}{2}$	124	30 59	49 44
42	$\mathfrak{t}$	$-\frac{2}{5}\frac{1}{5}$	$\bar{2}15$	31 14	25 20
43	$\mathfrak{K}$	$+\frac{3}{4}1$	344	31 59	67 16
44	m	∞	110	32 58	90 00
45	$\mathfrak{E}$	$-\frac{4}{5}\frac{3}{5}$	$\bar{4}35$	33 20	55 29
46	h	$0\frac{1}{5}$	015	34 37	26 12
47	$\mathfrak{Z}$	$-\frac{3}{4}\frac{1}{2}$	$\bar{3}24$	34 51	50 58
48	V	$-\frac{1}{3}\frac{1}{9}$	$\bar{3}19$	35 05	15 22
49	l	$-\frac{4}{3}1$	$\bar{4}33$	36 00	68 13
50	$\mathfrak{X}$	$+\frac{1}{6}\frac{1}{3}$	126	36 27	40 00
51	p	$+1$	111	38 11	68 47
52	k	$+\frac{3}{4}$	334	39 47	63 09
53	$\mathfrak{M}$	$-\frac{3}{2}1$	$\bar{3}22$	39 51	69 14
54	$\mathfrak{O}$	$+\frac{1}{8}\frac{1}{4}$	128	41 14	33 56
55	ξ	$-\frac{2}{3}\frac{1}{3}$	$\bar{2}13$	41 26	41 59
56	π	$+\frac{1}{2}$	112	42 45	54 02
57	$\mathfrak{l}$	$0\frac{1}{7}$	017	44 01	21 55
58	ε	$+\frac{3}{14}\frac{2}{7}$	3. 4. 14	44 07	38 52
59	$\mathfrak{B}$	$+\frac{3}{7}$	337	44 09	50 25
60	B	$\frac{3}{2}\infty$	320	44 12	90 00
61	r	$+\frac{4}{3}1$	433	45 00	70 45
62	Ω	$-1\frac{1}{2}$	$\bar{2}12$	45 35	55 20
63	O	$+\frac{1}{3}$	113	46 44	44 33
64	$\mathfrak{m}$	$-\frac{6}{5}\frac{3}{5}$	$\bar{6}35$	46 47	60 35
65	$\mathfrak{A}$	$-\frac{4}{11}\frac{1}{11}$	$\bar{4}$. 1. 11	47 03	15 07
66	χ	$+\frac{3}{2}1$	322	48 00	71 43
67	g	-21	$\bar{2}11$	49 12	72 07
68	μ	$-3\frac{3}{2}$	$\bar{6}32$	50 18	78 07
69	[illegible]	$+\frac{5}{3}1$	533	50 38	72 36
70	K	-63	$\bar{6}31$	51 18	84 07
71	q	$-\frac{3}{5}\frac{1}{5}$	$\bar{3}15$	51 27	33 01
72	δ	2∞	210	52 22	90 00
73	λ	$+\frac{1}{5}$	115	53 15	34 05
74	$\mathfrak{Q}$	$-\frac{5}{4}\frac{1}{2}$	$\bar{5}24$	53 22	59 29
75	$\mathfrak{T}$	$+\frac{1}{2}\frac{1}{3}$	326	54 09	49 03
76	W	$+3\frac{3}{2}$	632	54 15	79 07
77	i	$+21$	211	55 08	74 14
78	$\mathfrak{S}$	$-\frac{5}{2}1$	$\bar{5}22$	55 57	74 32
79	$\mathfrak{P}$	$+\frac{3}{8}\frac{1}{4}$	328	56 45	42 43
80	a	$-1\frac{1}{3}$	$\bar{3}13$	56 51	50 59
81	θ	$+1\frac{1}{2}$	212	57 32	62 04
82	$\mathfrak{m}$	$\frac{5}{2}\infty$	520	58 20	90 00
83	T	$+\frac{2}{3}\frac{1}{3}$	213	59 42	53 13
84	$\mathfrak{d}$	$\frac{8}{3}\infty$	830	59 58	90 00
85	o	-31	$\bar{3}11$	61 02	76 33

Forms of terlinguaite arranged in order of increasing ϕ value—Continued.

No.	Letter.	Symbol M_2. Gdt.	Symbol M_2. Miller.	ϕ	ρ
				° ′	° ′
86	*J*	$-\frac{2}{5}\frac{1}{15}$	$\bar{6}.1.15$	61 12	15 39
87	$\mathfrak{B}$	$-\frac{4}{5}\frac{1}{5}$	$\bar{4}15$	62 17	41 03
88	$\mathfrak{H}$	$+\frac{2}{5}\frac{1}{5}$	215	63 17	42 00
89	$\mathfrak{M}$	$-\frac{5}{9}\frac{1}{9}$	$\bar{5}19$	63 21	26 38
90	*s*	+31	311	64 22	77 56
91	*C*	$-\frac{4}{3}\frac{1}{3}$	$\bar{4}13$	65 21	58 17
92	*γ*	−41	$\bar{4}11$	67 50	79 27
93	*Γ*	$-1\frac{1}{5}$	$\bar{5}15$	68 36	47 59
94	$\mathfrak{O}$	+41	411	69 54	80 22
95	*E*	$-\frac{5}{3}\frac{1}{3}$	$\bar{5}13$	70 31	63 45
96	$\mathfrak{r}$	$+\frac{3}{7}\frac{1}{7}$	317	71 03	41 41
97	$\mathfrak{e}$	6∞	610	75 35	90 00
98	$\mathfrak{Z}$	$-2\frac{1}{4}$	$\bar{8}14$	77 48	67 20
99	*L*	$-\frac{1}{4}0$	$\bar{1}04$	90 00	2 13
100	*M*	$-\frac{1}{7}0$	$\bar{1}07$	90 00	5 16
101	$\mathfrak{M}$	$-\frac{1}{3}0$	$\bar{1}03$	90 00	8 59
102	*c*	0	001	90 00	15 37
103	*n*	$-\frac{1}{2}0$	$\bar{1}02$	90 00	20 39
104	$\mathfrak{x}$	$-\frac{3}{5}0$	$\bar{3}05$	90 00	26 56
105	$\mathfrak{u}$	$+\frac{1}{5}0$	105	90 00	28 28
106	*N*	$-\frac{2}{3}0$	$\bar{2}03$	90 00	30 47
107	$\mathfrak{o}$	$+\frac{1}{4}0$	104	90 00	31 18
108	$\mathfrak{y}$	$-\frac{3}{4}0$	$\bar{3}04$	90 00	35 11
109	$\mathfrak{p}$	$+\frac{1}{3}0$	103	90 00	35 39
110	*R*	$-\frac{4}{5}0$	$\bar{4}05$	90 00	37 37
111	$\mathfrak{z}$	$+\frac{3}{8}0$	308	90 00	37 40
112	*t*	$+\frac{1}{2}0$	102	90 00	43 06
113	*u*	−10	$\bar{1}01$	90 00	45 56
114	$\mathfrak{r}$	$+\frac{2}{3}0$	203	90 00	49 07
115	$\mathfrak{N}$	$+\frac{3}{4}0$	304	90 00	51 39
116	*Π*	$-\frac{6}{5}0$	$\bar{6}05$	90 00	52 20
117	*P*	$-\frac{4}{3}0$	$\bar{4}03$	90 00	55 47
118	*y*	+10	101	90 00	57 52
119	*Q*	$-\frac{3}{2}0$	$\bar{3}02$	90 00	59 23
120	$\mathfrak{B}$	$-\frac{5}{3}0$	$\bar{5}03$	90 00	62 21
121	$\mathfrak{m}$	$+\frac{4}{3}0$	403	90 00	63 46
122	*x*	−20	$\bar{2}01$	90 00	66 55
123	*F*	$+\frac{5}{3}0$	503	90 00	67 56
124	$\mathfrak{C}$	$-\frac{5}{2}0$	$\bar{5}02$	90 00	71 35
125	*z*	−30	$\bar{3}01$	90 00	74 43
126	*w*	+30	301	90 00	76 40
127	*S*	−40	$\bar{4}01$	90 00	78 38
128	*G*	+40	401	90 00	79 45
129	*θ*	−50	$\bar{5}01$	90 00	80 58
130	$\mathfrak{z}$	−70	$\bar{7}01$	90 00	83 36
131	*n*	+90	901	90 00	85 16
132	$\mathfrak{J}$	−12. 0	$\overline{12}$. 0. 1	90 00	86 18
133	$\mathfrak{k}$	+12. 0	12. 0. 1	90 00	86 26
134	*a*	∞0	100	90 00	90 00

FORMS AND CORRESPONDING ANGLES WITH (010) AS POLE.

In the following table the 134 forms are given with the angle values for each form when the crystal is set up with $b\{010\}$ as pole and a plane normal to the prisms as first meridian. As the crystals of terlinguaite are often extended in the direction of the b axis and this zone is, moreover, always striated and the only one which is nearly completely striated, it is often advantageous first to set up the crystal in this way and by the measurements then to find the correct orientation.

Forms of terlinguaite arranged in order of increasing ϕ value, with b (010) as pole and plane normal to prism zone as first meridian.

No.	Letter.	Symbol M_2.		ϕ		ρ	
		Gdt.	Miller.	°	′	°	′
1	b	0	010	....		90	00
2	σ	$-\frac{1}{5}1$	$\bar{1}55$	0	59	26	17
3	β	$-\frac{1}{5}$	$\bar{1}15$	0	59	67	57
4	ϕ	$-\frac{1}{4}1$	$\bar{1}44$	2	13	26	19
5	ι	$-\frac{1}{4}\frac{1}{2}$	$\bar{1}24$	2	13	44	41
6	H	$-\frac{1}{4}$	$\bar{1}14$	2	13	63	11
7	L	$-\frac{1}{4}0$	$\bar{1}04$	2	13	90	00
8	U	$-\frac{3}{11}\frac{1}{11}$	$\bar{3}.1.11$	4	29	79	36
9	M	$-\frac{1}{7}0$	$\bar{1}07$	5	16	90	00
10	A	$-\frac{2}{7}\frac{1}{7}$	$\bar{2}17$	5	27	73	57
11	X	$-\frac{1}{3}1$	$\bar{1}33$	8	59	26	34
12	ρ	$-\frac{1}{3}$	$\bar{1}13$	8	59	56	18
13	$\mathfrak{u}$	$-\frac{1}{3}\frac{1}{6}$	$\bar{2}16$	8	59	71	34
14	V	$-\frac{1}{3}\frac{1}{9}$	$\bar{3}19$	8	59	77	29
15	$\mathfrak{M}$	$-\frac{1}{3}0$	$\bar{1}03$	8	59	90	00
16	$\mathfrak{A}$	$-\frac{4}{11}\frac{1}{11}$	$\bar{4}.1.11$	11	11	79	46
17	$\mathfrak{L}$	$-\frac{2}{5}1$	$\bar{2}55$	13	48	26	57
18	$\mathfrak{t}$	$-\frac{2}{5}\frac{1}{5}$	$\bar{2}15$	13	48	68	32
19	J	$-\frac{2}{5}\frac{1}{15}$	$\bar{6}.1.15$	13	48	82	32
20	D	03	031	15	37	9	42
21	d	01	011	15	37	27	09
22	$\mathfrak{f}$	$0\frac{4}{5}$	045	15	37	32	40
23	$\mathfrak{g}$	$0\frac{3}{5}$	035	15	37	40	31
24	$\mathfrak{h}$	$0\frac{1}{2}$	012	15	37	45	44
25	$\mathfrak{a}$	$0\frac{4}{9}$	049	15	37	49	05
26	$\mathfrak{b}$	$0\frac{2}{5}$	025	15	37	52	03
27	f	$0\frac{1}{3}$	013	15	37	56	59
28	h	$0\frac{1}{5}$	015	15	37	68	42
29	$\mathfrak{l}$	$0\frac{1}{7}$	017	15	37	74	26
30	c	0	001	15	37	90	00
31	ψ	$-\frac{1}{2}1$	$\bar{1}22$	20	39	27	50
32	n	$-\frac{1}{2}0$	$\bar{1}02$	20	39	90	00
33	$\mathfrak{G}$	$+\frac{1}{10}1$	1.10.10	22	18	28	06
34	$\mathfrak{O}$	$+\frac{1}{8}\frac{1}{4}$	128	23	55	65	11
35	τ	$+\frac{1}{8}1$	188	23	55	28	24
36	$\mathfrak{M}$	$-\frac{5}{9}\frac{1}{9}$	$\bar{5}19$	24	09	78	24
37	$\mathfrak{N}$	$+\frac{1}{6}1$	166	26	29	28	36
38	$\mathfrak{X}$	$+\frac{1}{6}\frac{1}{3}$	126	26	29	58	52
39	ω	$-\frac{3}{5}1$	$\bar{3}55$	26	56	28	59
40	q	$-\frac{3}{5}\frac{1}{5}$	$\bar{3}15$	26	56	70	09

***Forms of terlinguaite arranged in order of increasing ϕ value, with b (010) as pole and plane normal to prism zone as first meridian*—Continued.**

No.	Letter.	Symbol M_2. Gdt.	Symbol M_2. Miller.	ϕ	ρ
				° ′	° ′
41	𝔵	$-\frac{3}{5}0$	$\bar{3}05$	26 56	90 00
42	𝔮	$+\frac{1}{5}1$	155	28 28	29 20
43	λ	$+\frac{1}{5}$	115	28 28	70 25
44	𝔫	$+\frac{1}{5}0$	105	28 28	90 00
45	ϑ	$+\frac{3}{14}\frac{2}{7}$	3. 4. 14	29 18	63 13
46	Δ	$-\frac{2}{3}1$	$\bar{2}33$	30 47	29 53
47	ξ	$-\frac{2}{3}\frac{1}{3}$	$\bar{2}13$	30 47	59 54
48	N	$-\frac{2}{3}0$	$\bar{2}03$	30 47	90 00
49	ζ	$+\frac{1}{4}1$	144	31 18	30 02
50	Σ	$+\frac{1}{4}\frac{1}{2}$	124	31 18	49 09
51	𝔬	$+\frac{1}{4}0$	104	31 18	90 00
52	Γ	$-\frac{3}{4}1$	$\bar{3}44$	35 11	28 51
53	Ξ	$-\frac{3}{4}$	$\bar{3}34$	35 11	38 51
54	ℨ	$-\frac{3}{4}\frac{1}{2}$	$\bar{3}24$	35 11	50 24
55	𝔶	$-\frac{3}{4}0$	$\bar{3}04$	35 11	90 00
56	ε	$+\frac{1}{3}1$	133	35 39	31 17
57	O	$+\frac{1}{3}$	113	35 39	61 16
58	𝔭	$+\frac{1}{3}0$	103	35 39	90 00
59	𝔈	$-\frac{4}{5}\frac{3}{5}$	$\bar{4}35$	37 37	46 30
60	𝔇	$-\frac{4}{5}\frac{1}{5}$	$\bar{4}15$	37 37	72 13
61	R	$-\frac{4}{5}0$	$\bar{4}05$	37 37	90 00
62	𝔓	$+\frac{3}{8}\frac{1}{4}$	328	37 40	68 10
63	𝔧	$+\frac{3}{8}0$	308	37 40	90 00
64	𝔘	$+\frac{2}{5}\frac{1}{5}$	215	38 49	72 30
65	𝔐	$+\frac{3}{7}$	337	40 07	56 26
66	𝔯	$+\frac{3}{7}\frac{1}{7}$	317	40 07	77 32
67	𝔍	$-\frac{6}{7}1$	$\bar{6}77$	40 13	32 54
68	Z	$+\frac{1}{2}1$	122	43 06	34 05
69	π	$+\frac{1}{2}$	112	43 06	53 32
70	𝔗	$+\frac{1}{2}\frac{1}{3}$	326	43 06	63 45
71	t	$+\frac{1}{2}0$	102	43 06	90 00
72	I	-13	$\bar{1}31$	45 56	13 19
73	e	-1	$\bar{1}11$	45 56	35 23
74	Ω	$-1\frac{1}{2}$	$\bar{2}12$	45 56	54 41
75	a	$-1\frac{1}{3}$	$\bar{3}13$	45 56	64 51
76	Υ	$-1\frac{1}{5}$	$\bar{5}15$	45 56	74 16
77	u	-10	$\bar{1}01$	45 56	90 00
78	v	$+\frac{3}{5}1$	355	46 52	35 51
79	Y	$+\frac{2}{3}1$	233	49 07	37 02
80	T	$+\frac{2}{3}\frac{1}{3}$	213	49 07	66 10
81	𝔯	$+\frac{2}{3}0$	203	49 07	90 00
82	𝔎	$+\frac{3}{4}1$	344	51 39	38 32
83	k	$+\frac{3}{4}$	334	51 39	46 43
84	𝔑	$+\frac{3}{4}0$	304	51 39	90 00
85	𝔪	$-\frac{6}{5}\frac{3}{5}$	$\bar{6}35$	52 20	53 23
86	Π	$-\frac{6}{5}0$	$\bar{6}05$	52 20	90 00
87	𝔔	$-\frac{5}{4}\frac{1}{2}$	$\bar{5}24$	53 42	59 04
88	l	$-\frac{4}{3}1$	$\bar{4}33$	55 47	41 18
89	C	$-\frac{4}{3}\frac{1}{3}$	$\bar{4}13$	55 47	69 13
90	P	$-\frac{4}{3}0$	$\bar{4}03$	55 47	90 00

Forms of terlinguaite arranged in order of increasing ϕ value, with b (010) as pole and plane normal to prism zone as first meridian—Continued.

No.	Letter.	Symbol M_2. Gdt.	Symbol M_2. Miller.	ϕ °	ϕ ′	ρ °	ρ ′
91	*A*	+13	131	57	52	17	12
92	*p*	+1	111	57	52	42	53
93	*θ*	$+1\frac{1}{2}$	212	57	52	61	41
94	*y*	+10	101	57	52	90	00
95	𝔎	$-\frac{3}{2}1$	$\bar{3}22$	59	23	44	07
96	*Q*	$-\frac{3}{2}0$	$\bar{3}02$	59	23	90	00
97	*E*	$-\frac{5}{3}\frac{1}{3}$	$\bar{5}13$	62	21	72	36
98	𝔅	$-\frac{5}{3}0$	$\bar{5}03$	62	21	90	00
99	*r*	$+\frac{4}{3}1$	433	63	46	48	07
100	𝔫	$+\frac{4}{3}0$	403	63	46	90	00
101	*χ*	$+\frac{3}{2}1$	322	66	02	50	33
102	*g*	−21	$\bar{2}11$	66	55	51	33
103	𝔍	$-2\frac{1}{4}$	$\bar{8}14$	66	55	78	45
104	*x*	−20	$\bar{2}01$	66	55	90	00
105	𝔐	$+\frac{5}{3}1$	533	67	56	52	45
106	*F*	$+\frac{5}{3}0$	503	67	56	90	00
107	*i*	+21	211	71	01	56	37
108	𝔖	$-\frac{5}{2}1$	$\bar{5}22$	71	35	57	20
109	𝔈	$-\frac{5}{2}0$	$\bar{5}02$	71	35	90	00
110	*μ*	$-3\frac{3}{2}$	$\bar{6}32$	74	43	51	19
111	*o*	−31	$\bar{3}11$	74	43	61	54
112	*z*	−30	$\bar{3}01$	74	43	90	00
113	*W*	$+3\frac{3}{2}$	632	76	40	54	49
114	*s*	+31	311	76	40	64	58
115	*w*	+30	301	76	40	90	00
116	*γ*	−41	$\bar{4}11$	78	38	68	14
117	*S*	−40	$\bar{4}01$	78	38	90	00
118	𝔒	+41	411	79	45	70	12
119	*G*	+40	401	79	45	90	00
120	*θ*	−50	$\bar{5}01$	80	58	90	00
121	*K*	−63	$\bar{6}31$	82	29	51	32
122	𝔷	−70	$\bar{7}01$	83	36	90	00
123	*η*	+90	901	85	16	90	00
124	𝔍	−12.0	$\overline{12}.0.1$	86	18	90	00
125	𝔨	+12.0	12.0.1	86	26	90	00
126	*j*	∞2	120	90	00	18	58
127	𝔳	$\infty\frac{3}{2}$	230	90	00	23	28
128	*m*	∞	110	90	00	32	57
129	*B*	$\frac{3}{2}\infty$	320	90	00	44	11
130	*δ*	2∞	210	90	00	52	21
131	𝔪	$\frac{5}{2}\infty$	520	90	00	58	21
132	𝔡	$\frac{8}{3}\infty$	830	90	00	60	10
133	𝔯	6∞	610	90	00	76	20
134	*a*	∞0	100	90	00	90	00

EGLESTONITE.

FORMS.

Eglestonite is known to occur in two forms and possibly a third. The distinction between the first two is not very clear and this, with the uncertainty regarding the third occurrence, justifies the statement that the mineral is found in only one really distinct form, as well developed crystals. The three forms into which the occurrences are divided are given below:

1. Distinct crystals are the characteristic form for eglestonite. They are found as such on nearly all of the specimens containing the mineral. These crystals, mostly equidiametrical, are rarely over 1 millimeter in diameter and usually about one-half millimeter and smaller. They occur in two distinct habits and also as a peculiarly distorted form, while the crystal described and illustrated by Moses has a different combination from those seen by the writer. These distinct crystals may thus be classed under three habits as follows—

(a) Rhombic dodecahedral habit.

(b) Octahedral habit.

(c) Distorted and thereby prismatic crystals.

These three habits are fully described on pages 155–156 and illustrated in figures 32–37.

One of our specimens shows a group of dull dark-gray crystals considerably rounded, which seem, however, to consist chiefly of faces of rhombic dodecahedra. On breaking these open the interior is seen to be of a yellow color, always dull and earthy looking, instead of bright and glistening like ordinary eglestonite. It seems to have altered or undergone some change and an analysis showed considerable differences from eglestonite (p. 146). It is possible that some new species is at hand or that the eglestonite has changed over to some other compound, forming a pseudomorph, but such difference could not be proved.

2. The mineral is sometimes found as a massive crust, not showing any crystal faces itself but occasionally including well-developed crystals. As the mineral is isometric it is not possible to say whether this crust is crystalline or truly amorphous. It often shows a conchoidal surface, which, however, seems to be a growth effect rather than an evidence of conchoidal fracture, as such a fracture can not be produced artificially in such development as is found on the natural mineral.

3. If eglestonite occurs as a powder this would be a distinct form, but no specimen that we have offers positive proof of the presence of powdery eglestonite. Some of the apparent powdery mixtures seem to contain terlinguaite and eglestonite, but for the present such a form of eglestonite must be considered as doubtful.

PHYSICAL PROPERTIES.

COHESION, ETC.

No cleavage could be detected. The fracture is uneven and apparently somewhat conchoidal. The usual surface obtained by breaking a crystal is uneven, but on some crystals there is a decided suggestion of a conchoidal surface. On some of the more massive eglestonite there were natural surfaces that were conchoidal, but it is difficult to say whether they were fracture surfaces or the natural crystalline surface of a mass of eglestonite.

The crystals are brittle, and no indications of plasticity or sectility were observed, though on such minute crystals as are available it is difficult to obtain satisfactory results.

As determined by Moses the hardness lies between 2 and 3.

DENSITY.

The great difficulty found in obtaining a large quantity of material free from calomel and mercury prevented any determinations of the specific gravity. Two determinations are given by Moses, 8.309 and 8.345.

LUSTER, COLOR, ETC.

The definition that was given by Moses of the luster of these crystals, brilliant adamantine to resinous, applies very well to the crystals that we have. This mineral differs from the others in that the luster is often decidedly resinous.

The first specimens received by us were dark brownish, but the last specimens were almost all of a light brownish yellow. They all darken quickly on exposure to light, becoming dark brown and finally black, but retaining their high luster. The streak is yellow, rapidly becoming black. Moses describes the streak as "in powder, greenish yellow to canary yellow, becoming quickly green and finally black on exposure to light." Repeated trials made by us failed to show any green color in any of the changes from yellow to black. In transmitted light the crystals are brown, hardly different from the color seen by reflected light. If a crystal could be viewed through parallel faces it would doubtless be transparent, but as they are they are translucent.

OPTICAL PROPERTIES.

The crystals are isotropic, and it was not found possible to measure the index of refraction. Several attempts were made to grind down and polish small prisms for a determination of the refractive index, but the smallness and brittleness of the crystals prevented any results from being obtained.

CHEMISTRY.

PYROGNOSTIC BEHAVIOR.

Eglestonite, on being heated in a closed tube, comports itself very much like terlinguaite, decrepitation and sublimation of calomel starting at the same time, mercury adding itself to the calomel and oxygen escaping. In vacuo, when slowly heated, the crystals become red as the first sublimate appears, soon black, then brown-red, cooling to orange-red and orange-yellow. The residue seems then to be mercuric oxide, as with terlinguaite, formed, with eglestonite, however, from mercurous oxide at the expense of half the mercury of the latter, a reaction that accords with the observation that no oxygen escapes till all the calomel and some mercury have sublimed. Finally, a reddish sublimate may appear immediately over the decomposing oxide, but it disappears on further heating.

BEHAVIOR TOWARD REAGENTS.

Hydrogen sulphide and ammonia blacken eglestonite at once, the latter reaction serving as a ready distinguishing test with respect to its occasionally immediate associate, terlinguaite. Hydrochloric and nitric acids decompose the mineral with separation of calomel. The filtrate from the hydrochloric acid solution contains no mercury. When cold dilute acetic acid is allowed to act, a reaction that proceeds quicker than with terlinguaite, calomel is left, and from the filtrate much more calomel is afforded by adding hydrochloric acid. The filtrate from this precipitate is free from mercury. These tests, confirmed by the analysis, show clearly the wholly mercurous nature of the compound, which is the first authentic instance of a mercurous oxychloride, native or artificial.

QUANTITATIVE COMPOSITION.

Analysis did not confirm the empirical formula $Hg_6Cl_3O_2$, deduced from McCord's analyses in the paper by Moses, a formula which, in fact, is invalidated by the qualitative data above communicated, since it calls for mercuric as well as mercurous mercury. The analyses were made in the main as for terlinguaite (p. 87) with the exception that the chlorine and mercury in the sublimate were each time determined, the separation being effected by sodium hydroxide. A little mercury went in this operation into solution with the chlorine, but was recovered.

In all cases the mercury is probably low, and calomel was present in sample 1 at least. It is probable that the oxygen was less accurately determined than the chlorine, but the effect of low mercury and the presence of calomel are better brought out by the ratio based on oxygen than on chlorine as unity. The formula plainly indicated is Hg_4Cl_2O, or $Hg_2O.2HgCl$, one that is in full agreement with the qualitative behavior of the mineral.

Analyses of eglestonite.

	1.	2.	3.
Hg	87.77	87.70	87.48
Cl	8.27	8.11	7.92
O	1.71	1.816	1.76
Nonvolatile	0.63	1.39	2.50
	98.38	99.016	99.66

Analyses of eglestonite calculated to gangue-free basis.

	1.	Atomic ratio.	2.	Atomic ratio.	3.	Atomic ratio.	Theory. (Hg_4Cl_2O).
Hg	88.33	4.11	88.94	3.87	89.73	3.99	90.21
Cl	8.32	2.18	8.23	2.02	8.12	2.03	7.99
O	1.72	1.	[a] 1.84	1.	1.80	1.	1.80
	98.37	....	99.01	....	99.65	....	100.00

[a] 1.90 by loss in weight of ignition tube.

1. Weight, 0.1195 gram. Selected crystals, nearly free from native mercury and calomel, which it is usually impossible to exclude completely. Nonvolatile gangue mostly calcite.
2. Weight, 0.1008 gram. Selected crystals.
3. Weight, 0.1198 gram.

The variations in the analytical data reported by Moses are so wide, as shown by the subjoined table, that the excellent agreement of his averages with the requirements of the formula $Hg_6Cl_3O_2$ can be due only to a fortuitous balancing of large errors. The oxygen values of the table, determined indirectly, are affected by whatever errors may be involved in the other determinations, and it is evident by inspection that these are large.

Analyses of eglestonite from paper by Moses.

	1.	2.	3.	4.	5.	Average.	Theory ($Hg_6Cl_3O_2$).
Hg	88.67	90.45	90.72	88.25	89.70	89.56	89.66
Cl	8.72	7.24	7.81	7.68	8.20	7.93	7.95
O	2.60	2.26	....	....	....	2.43	2.39
						99.92	100.00

Two other samples of what was supposed to be eglestonite were analyzed, more for purposes of identification than with expectation of getting results that would lead to a formula. One sample seemed pure, and was made up of a compacted mass of indeterminable crystals, gray-black on the surface but yellow within and dull. The other not well crystallized, and its freedom from calomel at least was

problematical. The analyses revealed a content in both chlorine and oxygen much in excess of those shown by the selected crystals of eglestonite, and indicated, if anything, a new oxychloride rather than a mixture of eglestonite with calomel. Indeed, the presence of eglestonite as a component seemed positively excluded by the high oxygen (2.16–2.36 per cent, approximately). The chlorine ran in one as high as 9.95 per cent. The results are more indicative, if not of a new species, of a mixture of terlinguaite and calomel, but the appearance of both specimens was distinctly against this.

CRYSTALLOGRAPHY.

GENERAL DESCRIPTION.

The minute crystals of eglestonite lose their bright color so rapidly on exposure to light that they can not be kept on exhibition, which is unfortunate, as the small crystals have such a striking color and high luster, and are so rich in faces, that they afford most interesting specimens for study. The distorted crystals, few of them 1 millimeter long, are extremely thin, scarcely thicker than a fine hair, and present an entirely different appearance from the common eglestonite crystals, which are generally very symmetrical in their development. In size, the crystals very rarely exceed 1 millimeter in thickness, and are usually one-half millimeter or less thick.

FORMS AND ANGLES.

Though minute, the crystals of eglestonite of the octahedral habit are rich in forms, a total of 20 having been determined for the mineral. Four of these, $a\{100\}$, $d\{110\}$, $n\{112\}$, and $s\{123\}$, were found by Moses on crystals of habit 1. The others are new for eglestonite. The total list of forms present on these crystals is shown below, new forms being indicated by stars:

a=100	*r=332	*Σ=145
d=110	*p=221	*F=126
*o=111	*ρ=441	s=123
*e=120	*i=189	*v=4. 7. 11
*f=130	*j=167	*M=234
*ϕ=116	*w=156	*l=347
n=112	*k=146	

The table following shows the average of the measured angles compared with the calculated ones.

Angle values of forms on eglestonite crystals.

[Starred letters indicate new forms.]

No.	Letter.	Number of measurements.	Symbol. Gdt.	Symbol. Miller.	Measured. ϕ		Measured. ρ		Calculated. ϕ		Calculated. ρ	
					°	′	°	′	°	′	°	′
1	*a*	....	0∞	100	....		90	00	....		90	00
2	*d*	....	∞	110	45	00	90	00	45	00	90	00
3	**o*	19	1	111	45	00	54	44	45	00	54	44
4	**e*	8	$\infty 2$	120	26	25	90	00	26	34	90	00
5	**f*	3	$\infty 3$	130	18	26	90	00	18	26	90	00
6	*ϕ	28	$\frac{1}{6}$	116	45	15	13	13	45	00	13	16
			16	161	9	29	80	34	9	28	80	40
7	*n*	52	$\frac{1}{2}$	112	45	00	35	17	45	00	35	16
			12	121	26	34	65	54	26	34	65	54
8	**r*	27	$\frac{3}{2}$	332	45	02	64	38	45	00	64	46
			$\frac{2}{3}1$	233	33	43	50	20	33	41	50	15
9	**p*	2	2	221	45	02	70	29	45	00	70	32
			$\frac{1}{2}1$	122	26	33	46	40	26	34	48	11
10	*ρ	1	4	441	45	02	79	28	45	00	79	58
11	**i*	3	$\frac{1}{8}\frac{9}{8}$	198	6	17	48	37	6	20	48	34
			89	891	41	38	84	48	41	38	85	15
12	**j*	1	$\frac{1}{7}\frac{6}{7}$	167	9	19	41	20	9	28	40	59
13	**w*	6	$\frac{1}{6}\frac{5}{6}$	156	11	38	40	15	11	19	40	21
			$\frac{1}{5}\frac{6}{5}$	165	9	39	50	48	9	28	50	35
14	**k*	2	$\frac{1}{6}\frac{2}{3}$	146	13	39	35	25	14	02	34	30
			$\frac{1}{4}\frac{3}{2}$	164	9	34	54	29	9	28	56	40
15	*Σ	1	45	451	38	52	81	35	38	40	81	08
16	**F*	1	26	261	18	23	80	08	18	26	81	01
17	*s*	81	$\frac{1}{3}\frac{2}{3}$	123	26	35	36	40	26	34	36	42
			$\frac{1}{2}\frac{3}{2}$	132	18	29	57	43	18	26	57	41
			23	231	33	40	74	33	33	41	74	30
18	**v*	12	$\frac{4}{11}\frac{7}{11}$	4.7.11	29	45	36	23	29	45	36	14
			$\frac{4}{7}\frac{11}{7}$	4.11.7	19	55	59	00	19	59	59	07
			$\frac{7}{4}\frac{11}{4}$	7.11.4	32	02	72	31	32	28	72	57
19	**M*	1	$\frac{1}{2}\frac{3}{4}$	234	32	22	41	46	33	41	42	02
20	**l*	2	$\frac{3}{4}\frac{7}{4}$	374	23	01	62	17	23	12	62	17
			$\frac{4}{3}\frac{7}{3}$	473	30	04	70	35	29	45	69	35

The common forms for eglestonite are seven in number, namely: *a*{100}, *d*{110}, *o*{111}, ϕ{116}, *n*{112}, *r*{332}, and *s*{123}. The forms which are somewhat less common but still occur so often that they can by no means be referred to as rare forms are, in approximately their order of importance, *v*{4.7.11}, *e*{120}, *w*{156}, *f*{130}, and *i*{198}. The following three forms were observed but twice: *p*{221}, *k*{146}, and *l*{374}; while the remainder, or ρ{441}, *j*{167}, Σ{451}, *F*{261}, *M*{234}, were observed but once. This last group, or those that were observed only once, constitute the rare forms.

Summary of eglestonite forms.

(a) Common forms	7
(b) Less common forms	8
(c) Rare forms	5
	20

DESCRIPTION OF COMMON FORMS.

$a\{100\}$, the cube, is present on all the octahedral crystals, while absent on all those of the dodecahedral habit. It is so minute that many faces give no signal on the goniometer.

$d\{110\}$, the rhombic dodecahedron, is the dominant face of habit 1, and on these crystals is invariably striated, many faces being built up of inscribed rhombs. On the octahedral crystals (habit 2) it is the second largest face, being smaller than the octahedron. On these crystals it is rarely striated.

$o\{111\}$, the octahedron, occurs as very minute faces on the dodecahedral crystals, but becomes the dominant form on the more complicated crystals of octahedral habit. No difference in character could be distinguished between the different faces of the octahedron.

$\phi\{116\}$ is present on all the octahedral crystals, and while invariably minute is one of the common forms of eglestonite.

$n\{112\}$ is one of the principal forms of this mineral and with the dodecahedron is present on all the crystals of eglestonite so far examined. It is usually a small face, though on the octahedral crystals it is third in size. The form is almost invariably striated.

$r\{332\}$ occurs often as minute faces on the dodecahedral habit, but as long line faces on the octahedral habit.

$s\{123\}$ is absent on the dodecahedral crystals, but occurs on all others as small faces. In all such octants of the crystal as were complete there were six faces of this form, indicating holohedral symmetry.

DESCRIPTION OF LESS COMMON FORMS.

All the measurements are here given for the less common forms.

Occurrence and measurements of less common forms (all new) on eglestonite crystals.

[Bold-faced figures give calculated values.]

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
$e\{120\}$	....	....	**26 34**	....
2	Poor	Minute	26 09	....
4	Poor	Minute	26 27	....
4	Poor	Minute	26 44	....
5	Poor	Minute	26 44	....
5	Poor	Line face	26 21	....
5	Poor	Line face	26 30	....
5	Poor	Minute	26 04	....
6	Poor	Minute	25 58	....

Occurrence and measurements of less common forms on eglestonite crystals—Continued.

Form and crystal No.	Reflection.	Size of face.	ϕ	ρ
			° ′	° ′
f{130}	....	....	**18 26**	....
3	Poor.....	Minute..........	18 21	....
3	Poor.....	Minute..........	18 42	....
5	Poor.....	Minute..........	18 14	....
p{221}	....	....	**45 00**	**70 32**
6	Poor.....	Broad line face..	45 02	70 29
p{122}	....	....	**26 34**	**48 11**
6	Poor.....	Line face........	26 33	46 40
i{198}	....	....	**6 20**	**48 34**
3	Poor.....	Line face........	6 19	48 26
6	Poor.....	Line face........	6 14	48 47
i{891}	....	....	**41 38**	**85 15**
5	Poor.....	Line face........	41 38	84 48
w{156}	....	....	**11 19**	**40 21**
6	Poor.....	Line face........	12 14	40 13
6	Poor.....	Line face........	11 02	40 16
w{165}	....	....	**9 28**	**50 35**
5	Poor.....	Minute..........	9 19	50 41
5	Poor.....	Minute..........	9 28	50 38
5	Poor.....	Minute..........	10 33	51 53
6	Poor.....	Minute..........	9 15	50 00
k{146}	....	....	**14 02**	**34 30**
2	Fair	Small...........	13 39	35 23
k{164}	....	....	**9 28**	**56 40**
2	Poor.....	Line face........	9 34	54 29
v{4.7.11}	....	....	**29 45**	**36 14**
5	Poor.....	Minute..........	30 01	36 16
5	Poor.....	Line face........	30 04	36 19
5	Poor.....	Minute..........	29 10	36 35
v{4.11.7}	....	....	**19 59**	**59 07**
5	Poor.....	Line face........	20 02	59 13
5	Poor.....	Line face........	19 35	58 38
5	Poor.....	Line face........	19 35	59 05
5	Poor.....	Line face........	19 53	58 36
5	Poor.....	Line face........	19 53	58 49
6(?)	Poor.....	Minute..........	21 46	60 13
6	Poor.....	Minute..........	20 34	59 40
v{7.11.4}	....	....	**32 28**	**72 57**
6	Poor.....	Line face........	31 49	72 40
6	Poor.....	Line face........	31 49	72 08
6	Poor.....	Minute..........	32 27	72 46
l{374}	....	....	**23 12**	**62 17**
5	Poor.....	Line face........	23 01	62 17
l{473}	....	....	**29 45**	**69 35**
5	Poor.....	Minute..........	30 04	70 35

DESCRIPTION OF RARE FORMS.

The following forms were observed once each:

Occurrence and measurements of rare forms on eglestonite crystals.

Symbol.	Crystal No.	Reflection.	Size of face.	Measured.		Calculated.	
				ϕ	ρ	ϕ	ρ
				° ′	° ′	° ′	° ′
ρ {441}	6	Poor...	Broad line face...	45 02	79 28	45 00	79 58
j {167}	5	Poor...	Minute...........	9 19	41 20	9 28	40 59
F {261}	6	Poor...	Minute...........	18 23	80 08	18 26	81 01
M {234}	2	Poor...	Minute...........	33 22	41 46	33 41	42 02
Σ {451}	5	Poor...	Line face........	38 52	81 35	38 40	81 08

The following forms were also observed once each, but the angles did not agree closely and the forms are more than doubtful. They are recorded only for reference: {343}, {447} or {559}, {551}, {235}, and {251}.

DISCUSSION OF FORMS.

Zone (100):(010) (No. 1); symbol, $\frac{k}{h}$.

Form	a 100	f 310	e 210	d 110	e 120	f 130	a 010
Symbol	0	1/3	1/2	1	2	3	∞
N_3	0	1/3	1/2 .	1 .	2	3	∞

The zone is normal.

Zone (001):(111):(110) (No. 2); symbol, $\frac{h}{l}$.

Form	a 001	ϕ 116	n 112	o 111	r 332	p 221	ρ 441	d 110
Symbol	0	1/6	1/2	1	3/2	2	4	∞
N_3	0	(1/6)	1/2 .	1	3/2	2	[4]	∞

In place of 4 or {441} we would expect {331}.

Values of ρ for the form {441}.

	° ′
Calculated {441}	79 58
Calculated {331}	76 00
Measured	79 28

Though {441} is considered certain, it is one of the rarest forms, having been noted but once. The form ϕ{116} is extra but is well established. Both of these forms, which cause a disturbance in the otherwise normal zone, are nearest the end members or members with the simplest indices, {001} and {110}.

Zone (101):(211) (No. 3); symbol, $\frac{k}{l}$.

Form	d 101	i 918	j 716	w 615	Σ 514	s 312	v 11.4.7	l 734	n 211	d 110
Symbol	0	1/8	1/6	1/5	1/4	1/2	4/7	3/4	1	∞

Dividing the series at 1/2, or {312}, we have:

	0	1/8	1/6	1/5	1/4	1/2		1/2	4/7	3/4	1	∞
$2v$..........	0	1/4	1/3	2/5	1/2	1	$2v$............	1	8/7	3/2	2	∞
$\frac{v}{v-1}$.........	0	1/3	1/2	2/3	1	∞	$v-1$...........	0	1/7	1/2	1	∞
N_3..........	0	1/3	1/2	2/3	1 ...	∞	N_2............	0	(1/7)	1/2	1 .	∞

The form {11.4.7} is extra, as might be expected, as it is very close to {312}. It is considered, however, as an established form (see p. 150 for angles).

Zone (160):(001) (No. 4); symbol, $\frac{h}{l}$.

Form........................	—	ϕ	F	k	w	j	a
	(160)	161	162	164	165	167	001
Symbol........................	(∞)	1	1/2	1/4	1/5	1/7	0
$2v$...........................	(∞)	2	1	1/2	2/5	2/7	0
N_3...........................	(∞)	2	1	1/2	(2/5)	(2/7)	0

The extra forms are {165} and {167}, both of which are well established. See discussion of preceding zone.

Zone (120):(001) (No. 5); symbol, $\frac{h}{l}$.

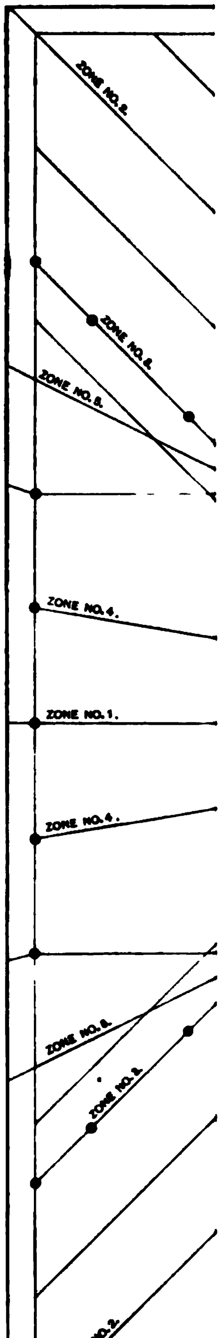
Form...........................	e	n	M	p	s	F	c
	120	121	243	122	123	126	001
Symbol...........................	∞	1	2/3	1/2	1/3	1/6	0
$2v$..............................	∞	2	4/3	1	2/3	1/3	0
N_3..............................	∞ .	2	[4/3]	1	2/3 .	1/3	0

In place of 4/3 {243}, we would expect 3/2 {364}, but the measurements show that {243} are the correct indices.

Combinations of forms on eglestonite crystals.

Letter.	Symbol.	Crystal No. —					
		1.	2.	3.	4.	5.	6.
a	100	....	a	a	a	a	a
d	110	d	d	d	d	d	d
o	111	o	o	o	o	o	o
e	120	....	e	....	e	e	e
f	130	....	....	f	....	f	....
ϕ	116	....	ϕ	ϕ	ϕ	ϕ	ϕ
n	112	n	n	n	n	n	n
r	332	r	r	r	r	r	r
p	221	....	....	....	....	....	p
ρ	441	....	....	....	....	....	ρ
i	189	....	....	i	....	i	i
j	167	....	....	....	....	j	....
w	156	....	....	....	....	w	w
k	146	....	k	....	....	....	....
Σ	145	....	....	....	....	Σ	....
F	126	....	....	....	....	....	F
s	123	....	s	s	s	s	s
v	4.7.11	....	....	....	....	v	v
M	234	....	M	....	....	....	....
l	347	....	....	....	....	l	....

U. S. GEOLOGICAL SU



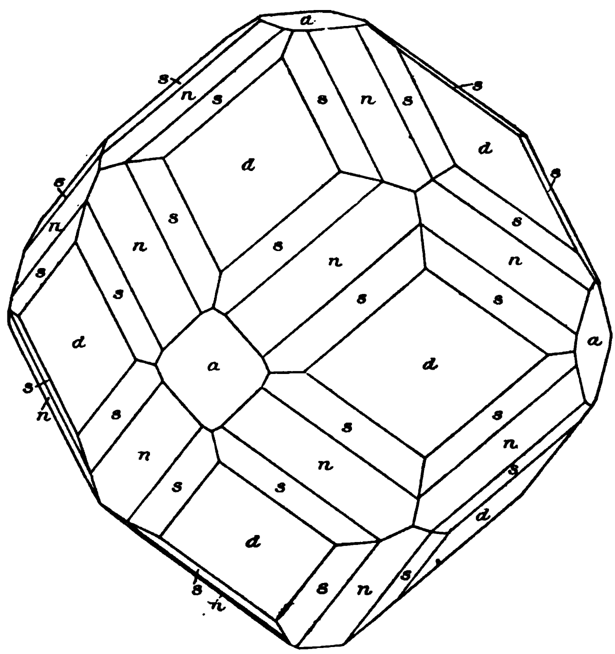


FIGURE 32.—Eglestonite, dodecahedral habit (after Moses): $a\{100\}$, $d\{101\}$, $n\{112\}$, $s\{123\}$.

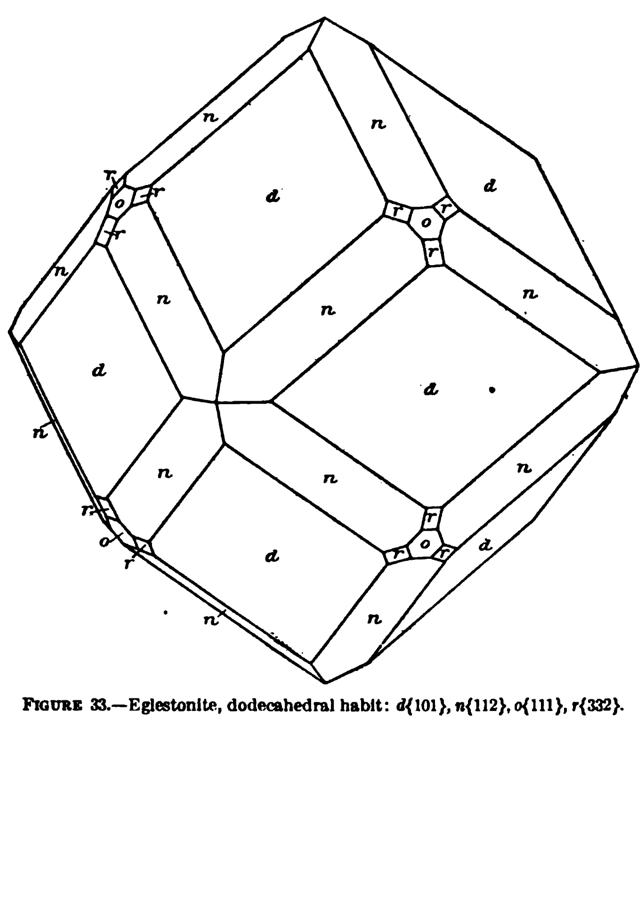


FIGURE 33.—Eglestonite, dodecahedral habit: $d\{101\}$, $n\{112\}$, $o\{111\}$, $r\{332\}$.

Crystal 1 is of the dodecahedral habit (see next page), the others of the octahedral habit. Notice the difference in the richness of combination as shown by crystals of the two habits.

ZONAL RELATIONS AND GNOMONIC PROJECTION.

The forms of eglestonite are arranged in a few well-defined zones, and one of these, the striated zone *nd*, contains nine forms. The

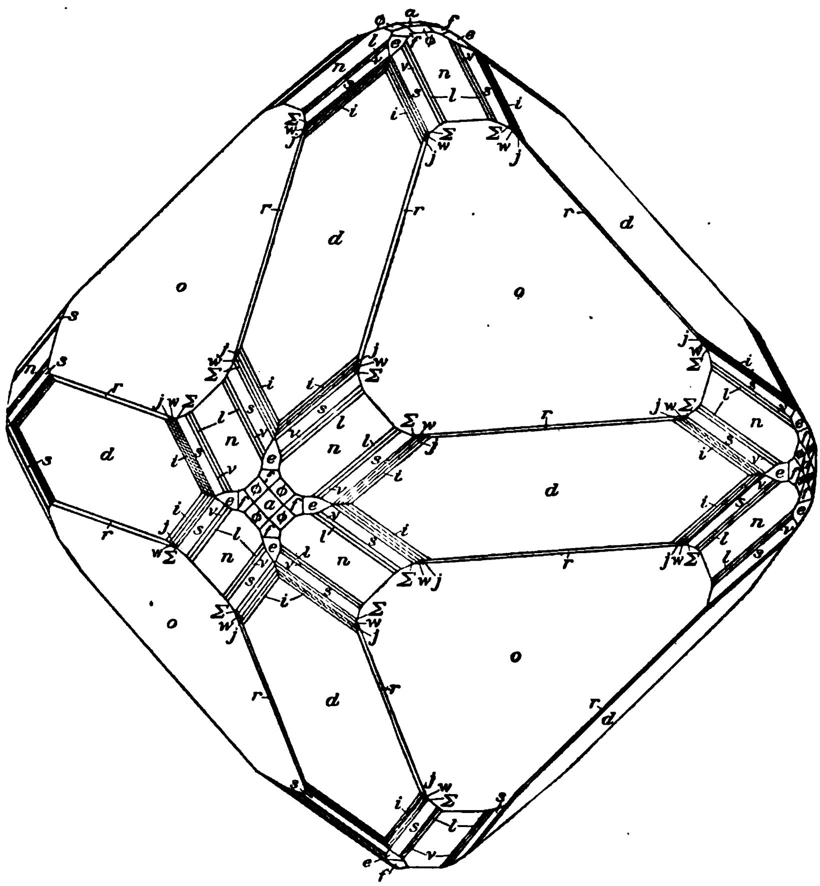


FIGURE 34.—Eglestonite crystal, octahedral habit: *a*{100}, *d*{101}, *o*{111}, *e*{120}, *f*{130}, ϕ{116}, *n*{112}, *r*{332}, *i*{189}, *j*{167}, *w*{156}, Σ{145}, *s*{123}, *v*{4.7.11}, *l*{347}.

prism zone with *a*, *d*, *e*, *f* is free from any striations, except that *d* is striated in the zone direction *dn*. The other three forms of this zone occur as bright even faces. Another fairly rich zone, free from striations, is (001), (116), (111), (332), (221), (441), (110). Other well-developed zones, (116), (216), (416), (516), (716), (100); (001), (216), (213), (212), (423), (211), (210); (918), (414), (324), (234), (144), (198) are all free from striæ. In fact, it is only the one zone *nd*, that is striated, and this is often very much striated. It

has been possible, however, to determine numerous forms in this zone, though a few of these belong to the rare forms, being noticed but once or twice. The forms determined, besides *n* and *d*, are {918}, {716}, {615}, {514}, {312}, {11.4.7}, {734}. Some of these are rather complex, but, as the discussion on page 151 showed, they all (except {11.4.7}) fall into the normal series and {11.4.7} is amply substantiated by the measurements given on page 150.

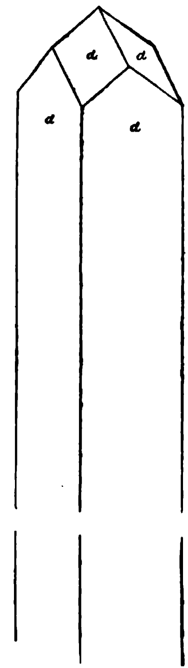


FIGURE 35.—Distorted eglestonite crystal: *d*{110}.

The zonal relations can be very well seen by reference to the gnomonic projection[a] shown in Plate VI. The numbered zones refer to the discussion on pages 151–152.

HABIT.

Crystals of eglestonite may be classed under three habits.

Habit 1. One form of this habit was described by Moses and is shown in figure 32, reproduced from his paper. This form was not observed by the writer.

All the eglestonite crystals that were on the specimens first received are of this dodecahedral habit (fig. 33). The crystals are simple in their combination, the only forms present being {110}, {111}, {112}, {332}. Of these {111} and {332} are very minute, while {110} is large and {112} small. Owing to the predominance of the rhombic dodecahedron, the habit is described as dodecahedral. The dodecahedron is invariably striated and built up of inscribed rhombs, while {112} is strongly striated. These crystals were all either brown or black when first received. The interior was often of a lighter brown, but none were such a light yellow brown as the crystals of the third or octahedral habit. In size the crystals are fairly uniform, the larger number being about 1 millimeter in diameter, though some were smaller, down to very minute.

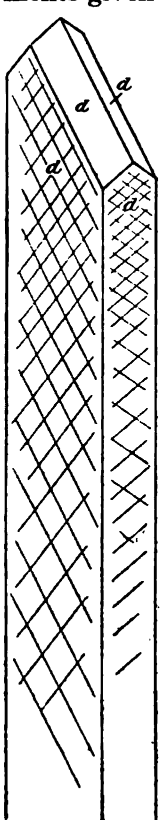


FIGURE 36.—Flattened eglestonite crystal: *d*{110}.

Habit 2. In the last package received were a number of eglestonite specimens, the crystals appearing entirely different from those earlier received, owing to the large development of the octahedron. Crystals of this habit are shown in figure 34. The octahedron, the largest

[a] The form {113} is shown in the gnomonic projection by mistake.

form, is bright and even, and no difference suggestive of tetrahedrism could be detected between the different faces. After the octahedron in size comes the dodecahedron and then the trisoctahedron {112}. These crystals are very rich in forms, a feature which also distinguishes them from those of the other habit. For comparison and to show how rich in faces these crystals are, the following table is given of the number of faces actually measured. The crystals are so minute that no readjustment of them on the wax was made after all faces possible were measured. Therefore only one-half of each crystal was measured.

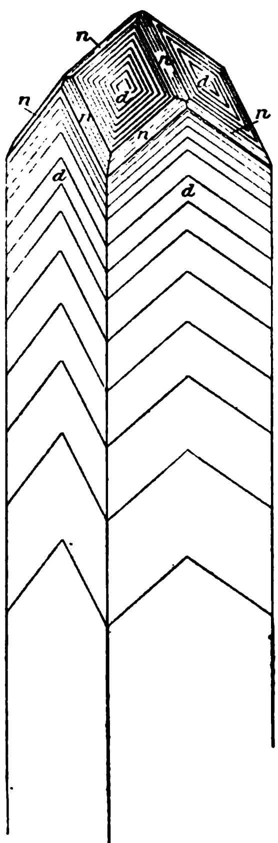


FIGURE 37.—Striated distorted eglestonite crystal: $d\{110\}$, $n\{112\}$.

Number of faces measured on half of each eglestonite crystal.

Crystal 1	13
Crystal 2	52
Crystal 3	41
Crystal 4	44
Crystal 5	92
Crystal 6	102

If the crystals were complete and had the entire number of faces for each form, they would have the following number of faces:

Number of faces indicated for complete eglestonite crystals.

Crystal 1	68
Crystal 2	266
Crystal 3	218
Crystal 4	170
Crystal 5	482
Crystal 6	410

Habit 3. Crystals of this habit are very long prismatic, becoming almost hairlike, owing to the distortion of $d\{101\}$. Three such crystals are shown in figures 35, 36, and 37.

DESCRIPTION OF CRYSTALS.

Such crystals as the one shown in figure 32, reproduced from the paper by Moses, were not observed by the writer. The common habit of the dodecahedral crystals is depicted in figure 33. The dodecahedron is always built up of inscribed rhombs, and the faces of $n\{112\}$ are strongly striated. Though some of these crystals are somewhat distorted, they usually are fairly constant in the relative development of their faces.

The octahedral crystals, such as Nos. 2, 3, 4, 5, and 6, are, however, the most interesting, as they are exceedingly rich in forms. Figure 34 shows an ideal development of crystal 5, all of the forms found on it being shown in the drawing. The large octahedral faces are bright and even, and the dodecahedron faces are but little striated, thus differing from those on the crystals of the dodecahedral habit. The faces of $n\{112\}$, however, are strongly striated, and it is, in fact, in the striated zone of (112) : (101) that so many of the faces lie. The cube faces, and those lying around the cube, such as ϕ, f, e, are all small but brilliant. The actual relations of the various forms and their mode of intersection with each other could not, of course, be actually seen, but the drawing is intended to represent the true combination as closely as it could be determined.

A number of curiously distorted crystals, those already mentioned under habit 3, were noticed on a very few specimens. They are distorted dodecahedrons resembling the drawing shown in figure 35. Some are still further distorted in that they are somewhat flattened as shown in figure 36. There is also a series of crossing striations on these faces, the lines being parallel to the edges $(1\bar{1}0) : (101) : (011)$ and $(110) : (101) : (0\bar{1}1)$, as shown in figure 36. Finally, some of the thicker of these distorted crystals showed the combination reproduced in figure 37, but here the lines or striæ on the dodecahedral faces have the appearance shown instead of as in the previous figure. These crystals are thus seen to be directly related to those of habit 1 (fig. 33).

CALOMEL.

FORMS.

Calomel is found in two forms.

1. Usually it is in distinct crystals, often twinned, and also irregularly grouped together. Most of the crystals are up to one-half centimeter in diameter, though a few are over 1½ centimeters thick. Some of the well-developed crystals are very minute. In general, two habits were noticed:

(*a*) Prismatic, mostly short prismatic.

(*b*) Equidimensional, the common habit.

2. Calomel is rather abundant on some of the specimens as a crystalline crust showing large cleavage faces. This crust in some parts is intimately mixed with eglestonite, giving it a yellow or brownish color. Many of the separate crystals (form 1) are situated on this crystalline crust.

PHYSICAL PROPERTIES.

COHESION, ETC.

These crystals possess good cleavage parallel to $a\{100\}$. The cleavage faces, however, are never perfectly smooth, but are slightly uneven, and on the goniometer give several faint reflections besides the one bright one. The cleavage, then, is much poorer than that of terlinguaite and montroydite, but is better than that of kleinite.

DENSITY.

Attention may be called to the fact, stated by Groth,[a] that the exact density of calomel is not known. The results obtained by different authors vary somewhat. Groth gives 6.71–7.18. Unfortunately the present material is not suited for a density determination. It was found on examining the material at hand that it all contained inclosed mercury, which sometimes became visible only on a fresh cleavage surface.

CRYSTALLOGRAPHY.

PREVIOUS PUBLICATION.

The writer had gone into a full discussion of the form system of calomel, taking the published data as well as his own results into consideration. A discussion of the forms, carried out in a way similar to that used for the already described minerals, led to several important conclusions, and the form system of calomel was thereby freed from many of its encumbering and questionable data. The entire paper has, however, been subjected to so much unavoidable delay that a description by other writers of these calomel crystals from Terlingua, Tex.,[b] has already appeared in print, though the present paper had been written a considerable time before the one referred to was published. In their paper Goldschmidt and Mauritz go very fully into a discussion of the form system of calomel, and arrive at results very similar to those obtained by the writer. He has, therefore, rewritten his crystallographical description of calomel, omitting the discussions and parts which would only result in needless repetition.

GENERAL DESCRIPTION.

The majority of the calomel crystals are directly on the soft earthy matrix, which usually has a deep red-brown color and contains only a very small amount of carbonate. The crystals on this matrix are generally equidiametral, several millimeters in diameter, and are

[a] Chemische Krystallographie, vol. 1, p. 214.

[b] Goldschmidt, V., and Mauritz, B., Über Kalomel. Zeitschr. Kryst. Min., vol. 44, 1907-8, p. 393.

usually twinned. The associated minerals are calcite, mercury, and eglestonite. The matrix specimens with calomel average about 5 to 6 centimeters in size and perhaps half as much in thickness. A few of the crystals on the matrix reach a diameter of 1 centimeter, though they are usually somewhat less than 5 millimeters thick. A few specimens show the calomel with other associations. It has been found with kleinite, montroydite, and terlinguaite. Here the crystals tend to a more prismatic habit and are much simpler in their combinations. A few large, loose crystals of simple habit and covered with mercury and eglestonite were also received. Three of the largest of these ose crystals measured (1) 15 by 14 by 11 millimeters, (2) 17 by 10 by 10 millimeters, and (3) 16 by 11 by 11 millimeters.

CALCULATION OF ELEMENTS.

From the measurements of the pyramids of the first and second order, those that gave good sharp signals were taken for a calculation of the *c* axis. There were not very many that allowed of sufficient accuracy of measurement to be used in calculating a fundamental constant, but 37 were taken and the value for *c* calculated from each angle value. These gave:

Values of c for calomel.

1.7239	1.7323	1.7227
1.7251	1.7364	1.7227
1.7262	1.7419	1.7085
1.7228	1.7229	1.7270
1.7262	1.7419	1.7332
1.7228	1.7175	1.7260
1.7239	1.7122	1.7260
1.7321	1.7199	1.7224
1.7332	1.7227	1.7148
1.7229	1.7185	1.7173
1.7117	1.7185	1.7170
1.7136	1.7254	
1.7173	1.7199	Av., 1.7234

The value found by the writer, namely $c = 1.7234$, agrees very well with existing determinations. Thus Goldschmidt and Mauritz give $c = 1.7236$ (Texas) and $c = 1.7220$ (Avala); and Schrauf gives $c = 1.7229$.

Taking an average of these determinations we have:

Determination, by average, of c for calomel.

56 measurements	1.7236
37 measurements	1.7234
9 measurements	1.7220
(50)[a] measurements	1.7229
Average	1.7232

[a] This weight is arbitrarily given to Schrauf's value.

This average value, $c = 1.7232$, is almost identical with the one of Schrauf generally adopted.

FORMS AND ANGLES.

The complete number of forms present on the twelve crystals measured is 29. Of these 21 have already been determined for calomel, leaving eight here described for the first time. But a careful study of these eight forms has shown that all except one must still be considered doubtful, and that they can not be classed with the typical forms of calomel. This is in part due to the striated character of the faces and in part to the twinning which is often present on these crystals. The only new form which is considered as well established is $K\{553\}$. The other seven are described fully below, but for the present they must be relegated to the already large class of uncertain forms.

The 21 known forms present on the crystals examined by the writer are:

c=001	s=021	p=331
a=100	d=031	v=153
g=160	a=113	n=132
q=015	i=112	ρ=135
γ=014	r=111	ϕ=131
t=012	o=221	π=124
e=011	μ=552	F=3. 5. 11

The eight forms, besides those given above, found on these crystals are:

j=0. 1. 12	H=1. 1. 24	K=553
Y=018	ϵ=117	S=3. 4. 10
Φ=035	T=334	

The form $z\{013\}$ was described by Moses as present on a crystal from Terlingua, but was not found by the writer. Goldschmidt and Mauritz found, in addition to those given above, $m\{110\}$ and $\delta\{016\}$, new.

The following table gives the average of the measured angles as compared with the values calculated ($c = 1.7232$). For the common forms, the average measured value is the average of only the best measurements.

Angle values for forms on calomel crystals.

[New forms are indicated by stars.]

No.	Letter.	Symbol.	Measured.		Calculated.	
			ϕ	ρ	ϕ	ρ
			° ′	° ′	° ′	° ′
1	*c*	001	....	0 00	....	0 00
2	*a*	100	....	90 00	90 00	90 00
3	*g*	160	9 31	88 08	9 27	90 00
4	**j*	0.1.12	0 00	8 22	0 00	8 10
5	**Y*	018	0 00	12 12	0 00	12 09
6	*q*	015	0 00	19 01	0 00	19 01
7	*γ*	014	0 00	23 15	0 00	23 18
8	*t*	012	0 00	40 45	0 00	40 40
9	**Φ*	035	0 00	45 20	0 00	45 57
10	*e*	011	0 00	59 52	0 00	59 52
11	*s*	021	0 00	73 52	0 00	73 49
12	*d*	031	0 00	79 07	0 00	79 03
13	**H*	1.1.24	45 00	5 48	45 00	5 48
14	**ε*	117	44 57	19 21	45 00	19 12
15	*a*	113	45 10	39 07	45 00	39 05
16	*i*	112	45 17	50 30	45 00	50 37
17	**T*	334	45 00	60 17	45 00	61 19
18	*r*	111	44 59	67 45	45 00	67 41
19	**K*	553	45 46	75 53	45 00	76 10
20	*o*	221	44 55	78 15	45 00	78 24
21	*μ*	552	45 46	80 47	45 00	80 40
22	*p*	331	44 58	82 07	45 00	82 12
23	*v*	153	11 22	71 19	11 19	71 08
24	*ρ*	135	18 24	47 26	18 26	47 27
25	*n*	132	18 20	70 08	18 26	69 50
26	*ψ*	131	18 18	79 38	18 26	79 36
27	*π*	124	26 27	43 55	26 34	43 55
28	*F*	3.5.11	31 29	42 38	30 58	42 24
29	**S*	3.4.10	36 32	41 37	36 52	40 45

DESCRIPTION OF FORMS.

Of the known forms found by the writer and given in the foregoing table, Goldschmidt and Mauritz exclude $g\{160\}$, $\mu\{552\}$, and $F\{3.5.11\}$. Though the prism $g\{160\}$ was noted by the writer as two faces, they were both very rounded and uneven and the form should not be included in the typical forms of calomel. The form $\mu\{552\}$, however, should be included, as it was noted as a small narrow face in the zone *cm*, the measured and calculated angles agreeing well. The form $F\{3.5.11\}$, first described by Websky[a] without any angles, should also be included, the form being substantiated by the measurements following.

[a] Monatsber. K. Akad. Wiss., Berlin, 1877, p. 461.

Occurrence and measurements of the form F {3.5.11}, calomel.

Crystal No.—	Reflection.	Size of face.	ϕ (30° 58′ calc.).	ρ (42° 24′ calc.).
			° ′	° ′
6	Poor......	Line face.......	30 54	43 13
6	Poor......	Line face.......	32 41	42 00
8	Poor......	Line face.......	32 19	43 41
9	Poor......	Line face.......	30 00	41 39

For the new forms all the measurements are given in the following pages.

j {0.1.12} is a dome characteristic for the crystals from Terlingua, the true symbol of which is in doubt, since it is always strongly striated. The form was also noted by Goldschmidt and Mauritz, without, however, the variation in angles found by the writer, their measurements indicating rather constantly the form {0.1.13}. All of the measurements made by the writer are here given in increasing values. It is, of course, possible that more than one form is present, as is suggested by a comparison with the calculated values given for different forms in the last column. Being such a common form for these crystals, it is included in the list of forms for calomel from Terlingua, with a question mark to show that its correct symbol is not yet determined.

Occurrence and measurements of ρ for j {0.1.12}.

Crystal No.—	Reflection.	Size of face.	Measured.	Calculated.
			° ′	
10	Poor......	Line face.......	5 39	
10	Poor......	Line face.......	6 04	
6	Poor......	Line face.......	6 14	6° 33′ for {0.1.15}.
6	Poor......	Line face.......	6 28	
6	Poor......	Line face.......	6 40	
8	Poor......	Line face.......	6 50	7° 01′ for {0.1.14}.
11	Poor......	Line face.......	7 15	
12	Poor......	Line face.......	7 15	[a] 7° 33′ for {0.1.13}.
11	Poor......	Line face.......	7 43	
11	Poor......	Line face.......	7 44	
6	Poor......	Line face.......	8 36	8° 10′ for {0.1.12}.
6	Poor......	Line face.......	8 41	
1	Poor......	Line face.......	8 41	8° 54′ for {0.1.11}.
4	Poor......	Line face.......	8 44	
4	Poor......	Line face.......	8 50	
6	Poor......	Line face.......	9 04	
6	Poor......	Line face.......	9 06	
3	Poor......	Line face.......	9 26	
6	Fair.......	Line face.......	10 03	9° 47′ for {0.1.10}.
3	Poor......	Line face.......	10 07	
9	Poor......	Line face.......	10 18	
6	Poor......	Line face.......	10 23	10° 50′ for {0.1.9}.
2	Good.....	Broad..........	10 23	
10	Poor......	Line face.......	10 34	
Average	....	....	8 22	

[a] Goldschmidt and Mauritz measure: 7° 22′, 7° 46′, 7° 56′, 7° 23′, 7° 30′, 7° 30′.

The form $Y\{018\}$ was observed on two crystals as the merest line faces. The character of the faces was, however, too poor to allow of their definite determination. The form $\{018\}$ also lies very near to that of $\{0\bar{2}1\}$ in twin position and may, perhaps, belong to that form.

Occurrence and measurements of Y {018}, calomel.

Crystal No.	Reflection.	Size of face.	ρ (12° 09′ calc.).
			° ′
9	Poor.......	Line face.......	12 00
10	Poor.......	Line face.......	12 23

The dome $\Phi\{035\}$ occurred once on crystal 6, as a mere line face or as fine striæ; ρ measured 45° 20′ (calc. 45° 57′). The position of $\{035\}$ on the gnomonic projection is likewise very close to that of $\{021\}$ in twin position, and like $\{018\}$ may belong to that form.

The measured angles for $T\{334\}$ vary considerably from the calculated values, and the form is therefore considered doubtful:

Occurrence and measurements of T {334} (?), calomel.

Crystal No.	Reflection.	Size of face.	ϕ (45° 00′ calc.).	ρ (61° 19′ calc.).
			° ′	° ′
5	Poor......	Small..........	45 00	60 28
7	Poor......	Line face......	45 00	60 05

$K\{553\}$ occurs on crystal 4 as a narrow face giving a fairly good reflection, in the zone *cm* between (111) and $(55\bar{2})$. Calculated, $\rho = 76°\ 10'$, measured $\rho = 75°\ 53'$. The face is shown in figure 41.

One face of S {3.4.10} was observed. It lies in the zone (124) and (113), but on account of its somewhat complex symbol and not very close agreement in angles is included only with a query and is omitted from the list of well-established forms:

Occurrence and measurements of S {3.4.10} (?), calomel.

Crystal No.	Reflection.	Size of face.	ϕ (36° 52′ calc.).	ρ (40° 45′ calc.).
			° ′	° ′
4	Poor......	Very narrow....	36 32	41 37

The form $H\{1.1.24\}$ seems to lie in the zone $j'j$, the striated dome with symbol very near to {0.1.12}, but this could not definitely be determined on account of the striated character of the faces.

Occurrence and measurements of H {1.1.24}, calomel.

Crystal No.	Reflection.	Size of face.	ϕ (45° 00′ calc.).	ρ (5° 48′ calc.).
			° ′	° ′
3	Poor......	Minute and very narrow.	45 00	5 56
4	Poor......	Minute and very narrow.	45 00	6 20
6	Poor......	Minute and very narrow.	45 00	5 30
10	Poor......	Minute.........	45 00	5 57
10	Fair.......	Minute.........	45 00	5 16

On crystal 10 two faces of the form are present, of which only one could be accurately measured. This gave $\rho=5°\ 57'$, and the other face gave a fairly distinct signal, but the basal plane gave two signals, and it was not possible to determine which was the correct one to use. The two measurements gave 5° 01′ and 5° 30′, the average of which, or 5° 16′, is the value given for the second face. The reflections were all too poor to decide definitely the indices of the form. But as the form occurs a number of times it is included in the list of forms (p. 171), with a query to indicate that its correct symbols are still to be determined.

The form ϵ {117} occurs once as a medium-sized face on a crystal referred to below as No. 13, which shows a large base, a few pyramids of the first order and {113}. Measurements of {113} and {014} served to establish the correct orientation of the crystal. A study of the gnomonic projection of twinned crystals has shown that the form {117} is so near to {135} in twinned position (twinning plane e {101}) that it is questionable whether the face is not in reality {135} instead of {117}. Some of these twin crystals are rather complex, being usually interpenetrating, with but a very small part of the twinned crystal appearing. The indices {117} are very unusual for calomel, and the form is therefore considered doubtful.

Occurrence and measurements of ε {117}, calomel.

Crystal No.	Reflection.	Size of face.	ϕ (45° 00′ calc.).	ρ (19° 12′ calc.).
			° ′	° ′
3	Poor......	Narrow........	44 11	19 57
7	Poor......	Narrow........	45 00	19 16
13	Fair.......	Medium........	45 39	18 50

DISCUSSION OF FORMS.

The main part of the discussion of the forms of calomel has, as already mentioned, been omitted from this paper. Only such parts as belong to the new forms and to one old form are here given.

Zone (001) : (011).

Form	*c* 001	*j* 0.1.12	*Y* 018	*δ* 016	*q* 015	*γ* 014	*z* 013	*t* 012	*Φ* 035	*e* 011
Symbol	0	1/12	1/8	1/6	1/5	1/4	1/3	1/2	3/5	1
$\frac{1-v}{1+v}$	1	11/13	7/9	5/7	2/3	3/5	1/2	1/3	1/4	0
$\frac{v}{1-v}$	∞	11/2	7/2	5/2	2	3/2	1	1/2	1/3	0
$v-1$	∞	9/2	5/2	3/2	1	1/2	0			
$\frac{2v-1}{2}$	∞	4	2	1	1/2	0				
N_2	∞	(4)	2	1	1/2	0				

The form {0.1.12} does not fit in the series. Of the other forms the new doubtful ones {018} and {035} pass well in the zone.

Zone (001) : (110).

Form	*c* 001	*H* 1.1.24	*ε* 117	*h* 114	*a* 113	*i* 112	*T* 334	*r* 111	*K* 553	*o* 221	*μ* 552	*p* 331	*m* 110
Symbol	0	1/24	1/7	1/4	1/3	1/2	3/4	1	5/3	2	5/2	3	∞

Dividing the zone at 1 and considering only the first part, we have:

	0	1/24	1/7	1/4	1/3	1/2	3/4	1
$\frac{v}{1-v}$	0	1/23	1/6	1/3	1/2	1	3	∞
N_3	0	(1/23)	(1/6)	1/3	1/2 .	1 . .	3	∞

The two forms {1.1.24} and {117}, already considered as doubtful, do not fit in well. The last part of the zone gives:

	1	5/3	2	5/2	3	∞
$v-1$	0	2/3	1	3/2	2	∞
N_3	0..	2/3	1	3/2	2 .	∞

Zone (102):(011).

Form	*t* 102	*α* 113	*S* 3.4.10	*F* 3.5.11	*π* 124	*ρ* 135	*e* 011
Symbol	0	1/3	2/5	5/11	1/2	3/5	1
$\frac{v}{1-v}$	0	1/2	2/3	5/6	1	3/2	∞
N_3	0 .	1/2	2/3	(5/6)	1	3/2..	∞

The form {3.5.11}, very near {124}, is extra. The form *S* {3.4.10} fits in well, but is, as already stated, considered as doubtful.

A few words about one old form, classed as doubtful by Goldschmidt and Mauritz. This form, *β* {054} given by Traube,[a] should be {043}. This is brought out by the discussion of the zone.

[a] Zeitschr. Kryst. Min., vol. 14, 1888, p. 571.

Zone (010):(011).

Form	*a*	*k*	*d*	*s*	*β*	*e*
	010	041	031	021	054	011
Symbol	∞	4	3.	2	5/4	1
$v-1$	∞	3	2	1	1/4	0

If the form *β* were {043}, then we would have—

$$\infty \quad 3 \quad 2 \quad 1 \quad 1/3 \quad 0$$

which would compare better with the normal series N_3.

Traube's measurements are:

	°	′
(104):(504):		
Measured	40	51
Calculated for (504)	41	47
Calculated for (403)	41	03
(504):(201):		
Measured	8	29
Calculated for (504)	8	44
Calculated for (403)	9	19

The variations are too great, however, to consider the form as definitely established, though {403} seems more probable than {504}.

Combinations of forms on calomel crystals.

No.	Letter.	Symbol.	Crystal No. — 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	*c*	001	(*c*)	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*
2	*a*	100	*a*	*a*	*a*	*a*	*a*	*a*	*a*	....	....	....	*a*	....
3	*g*	160	....	....	....	....	....	*g*	....	....	....	....	....	....
4	*j*	0.1.12	*j*	*j*	*j*	*j*	*j*	*j*	*j*	*j*	*j*	*j*	*j*	*j*
5	*Y*	018	....	....	....	....	....	....	....	....	*Y*	*Y*	....	....
6	*q*	015	....	....	....	*q*	....	....	*q*	....	....	*q*	....	....
7	*γ*	014	*γ*	*γ*	*γ*	*γ*	*γ*	*γ*	*γ*	*γ*	*γ*	*γ*	*γ*	*γ*
8	*t*	012	*t*	*t*	*t*	*t*	*t*	*t*	*t*	....	*t*	*t*	*t*	*t*
9	*Φ*	035	....	....	....	....	....	*Φ*	....	....	....	....	....	....
10	*e*	011	*e*	*e*	*e*	*e*	*e*	....	*e*	*e*	*e*	*e*	*e*	*e*
11	*s*	021	*s*	*s*	*s*	*s*	*s*	*s*	*s*	*s*	*s*	*s*	*s*	*s*
12	*d*	031	*d*	....	*d*	*d*	*d*	*d*	*d*	*d*	*d*	....	*d*	*d*
13	*H*	1.1.24	....	....	....	*H*	....	*H*	....	....	....	*H*	....	....
14	*ε*	117	....	....	*ε*	....	....	....	*ε*	....	....	....	....	....
15	*α*	113	*α*	....	*α*	*α*	*α*	*α*	*α*	*α*	*α*	*α*	*α*	*α*
16	*i*	112	....	....	*i*	....	*i*	*i*	*i*	*i*	....	....	*i*	....
17	*T*	334	....	....	....	....	....	....	*T*	....	....	....	....	....
18	*r*	111	*r*	*r*	*r*	*r*	*r*	*r*	*r*	*r*	*r*	....	*r*	....
19	*K*	553	....	....	....	*K*	....	....	....	....	....	....	....	....
20	*o*	221	....	....	*o*	....	*o*	*o*	....	*o*	....	....	....	....
21	*μ*	552	....	....	....	*μ*	....	....	....	....	....	....	....	....
22	*p*	331	....	....	*p*	....	*p*	*p*	....	....	....	....	*p*	....
23	*v*	153	*v*	*v*	*v*	*v*	*v*	*v*	*v*	*v*	*v*	*v*	*v*	....
24	*ρ*	135	....	*ρ*	*ρ*	*ρ*	*ρ*	*ρ*	*ρ*	*ρ*	*ρ*	*ρ*	....	*ρ*
25	*n*	132	....	*n*	*n*	*n*	*n*	*n*	....	*n*	*n*	*n*	*n*	....
26	*ψ*	131	....	*ψ*	....	....	*ψ*	....	....	*ψ*	*ψ*	....	....	....
27	*π*	124	*π*	*π*	*π*	*π*	*π*	*π*	*π*	*π*	*π*	*π*	....	*π*
28	*F*	3.5.11	....	....	....	....	....	*F*	....	*F*	*F*	....	....	....
29	*S*	3.4.10	....	....	....	*S*	....	....	....	....	....	....	....	....

HABIT.

1. *Prismatic habit.*—Crystals of a prismatic habit are very rare. A crystal of this habit with *c*, *a*, α, *r*, and *z*{013} was figured and described by Moses. A few prismatic crystals were noticed by the writer on one of the specimens. They were very small and showed *ca* with possibly *m*{110} and *s*{021}, as very small faces, though the edges and corners were so rounded and uneven as to make the identification of any forms almost impossible. This habit, therefore, seems to be a very rare one for calomel of this locality.

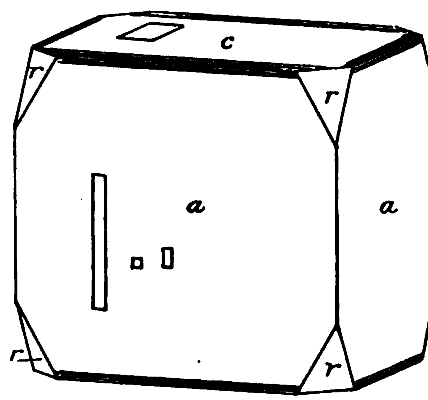


FIGURE 38.—Calomel: *a*{010}, *c*{001}, *r*{111}.

2. *Equidiametral habit.*—Almost all of the crystals are of this habit and most of them are very rich in faces. As a sort of intermediate between these two habits there may be described two forms of crystals. The one, which is the habit of the very large crystals, has *a* and *c* large with the corners truncated by *r*{111}. Some pyramids of the first order, as possibly {014} and {011}, are probably also present, but the edges are too rounded for any determination. These crystals are covered with eglestonite and mercury and many appear considerably etched. Many faces of {100} are finely striated vertically. On one specimen etch faces were noticed on (100). Their appearance is shown in figure 38. In general they are slightly elongated in the vertical direction. The other intermediate habit was noticed on a number of the crystals that are on the pink rock, heavily impregnated with calomel. The crystals are very rounded and uneven and many seem to be attached in parallel position. The prism *m*{110} seems to be present. The other forms are *c*, *a*, and *r*. Their general appearance is shown in figure 39.

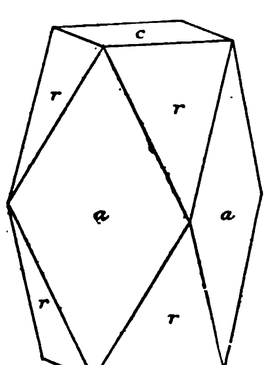


FIGURE 39.—Calomel: *a*{010}, *c*{001}, *r*{111}.

TWIN CRYSTALS.

Goldschmidt and Mauritz do not mention any twinning in their description of the crystals from Terlingua. Many of those examined by the writers are twinned, and others are placed together in irregular position. Such an irregular grouping is shown in figure 41, and a

study of the gnomonic projection shows that the displacement of the two parts is irregular and is not to be ascribed to twinning. On the other hand, a twinned crystal is shown in figure 43.

The twinning plane is $e\{101\}$, and the crystals are usually more or less interpenetrating. While the line of demarcation is very prominent in some crystals, in others it is not, and when, in addition, the crystals are very minute it often becomes questionable whether a given face belongs to the twinned or the untwinned crystal.

DESCRIPTION OF CRYSTALS.

Crystal 1 is incomplete and has $\{010\}$, $\{124\}$, $\{113\}$, and $\{014\}$ developed as large faces, the other forms being present as very subordinate ones. The crystal shows the new form $\{0.1.12\}$.

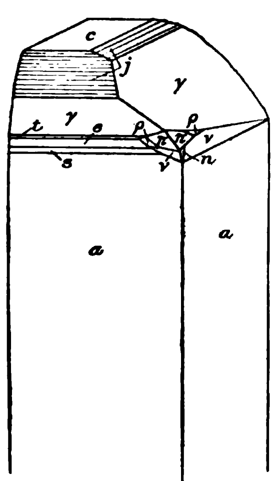


FIGURE 40.—Calomel crystal 2: $j\{0.1.12\}$, $r\{014\}$, $t\{012\}$, $e\{011\}$, $s\{021\}$, $\rho\{124\}$, $a\{135\}$, $n\{132\}$, $v\{153\}$.

Crystal 2 is a cleavage part of a large crystal and is shown in figure 40. In its present shape it has a prismatic appearance, while the complete original crystal was probably about equidiametrical. It shows a large face of the new form $\{0.1.12\}$ and a smaller face of the same form, both very much striated.

Crystal 3 is incomplete and shows a large base with the pyramid $\{111\}$ next in size. A number of small faces give readings which do not agree with any known form but are too poorly developed to warrant any description. The prism $g\{160\}$ seems to be present as a narrow, uneven face. It measures: $\phi=9°$ $32'$ (calc. $9°$ $27'$); $\rho=87°$ $15'$ (calc. $90°00'$). The three new forms $\{0.1.12\}$, $\{117\}$, and $\{1.1.24\}$ are present. The form $\{117\}$ is present on a portion of the crystal projecting above the main part, and probably belongs to a face of $\{135\}$ in twin position.

Crystal 4 consists essentially of two parts which are slightly displaced in reference to each other. After each part had been measured to determine the forms present, the entire group was measured as one unit. In figure 41 the larger part is set up in normal position. By plotting the readings it can be seen that there is no definite relation between the two parts; they are not twinned, but the one part has become shifted with regard to the other. The rare form $q\{015\}$ is present as a line face giving a fair reflection, with $\rho=19°$ $52'$ (calc. $19°$ $01'$). The rare form $\mu\{552\}$ is also present as a narrow face giving a fair reflection. It measures: $\phi=45°$ $46'$ (calc. $45°$ $00'$); $\rho=80°$ $47'$ (calc. $80°$ $40'$). It follows the new form $K\{553\}$ and lies between (111) and $(11\bar{1})$. The new form $S\{3.4.10\}$ occurs as a nar-

row face broader than a line face but narrower than the other forms in the same zone. Only one face of the form is present. Between (101) and (111) is a rounded line face which gives a band of signals, so that no accurate measurement was possible. The middle of the band of signals gave a measurement agreeing for the form {122}, but as this would be a new form, and it is questionable whether there really is a plane face present the form is not put forward. It measured: $\phi = 27° \ 48'$ (calc. {122} $26° \ 34'$); $\rho = 62° 11'$ (calc. {122} $62° \ 34'$). The new form *H*{1.1.24} is present as a very small face, striated nearly normal to its intersection with the base. This rendered it difficult to measure the ϕ angle, though the ρ angle could be measured accurately.

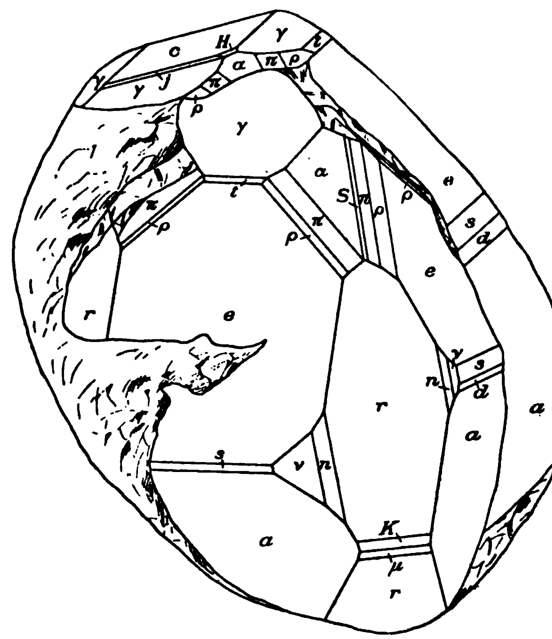


FIGURE 41.—Calomel crystal 4: *H*{1.1.24}, *α*{113}, *K*{553}, *μ*{552}, *S*{3.4.10}.

Crystal 5 (fig. 42) shows the rare form *p*{331} as a minute face giving a poor reflection. It measured: $\rho = 81° \ 57'$ (calc. $82° 12'$). The new form *T*{334} is present on this crystal as a small face.

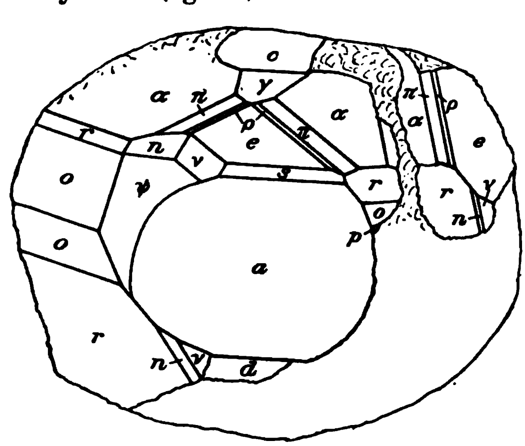


FIGURE 42.—Calomel crystal 5: *p*{331}, *ψ*{131}.

Crystal 6 is the most interesting of the entire series. It measures about 4 by 5 by 7 millimeters and consists essentially of five different crystals twinned on each other. Three of these are large and well developed, while the remainder are much smaller. The new forms *Φ*{035}, *j*{0.1.12}, *H*{1.1.24} occur as well as the established but rare forms *p*{331}, *g*{160}, and *F*{3.5.11}. For *p*{331} there was

measured $\rho = 82° \ 11'$, $81° \ 52'$ (calc. $82° \ 12'$). For $g\{160\}$, which was broken and uneven, there was measured: $\phi = 9° \ 30'$ (calc. $9° \ 27'$); $\rho = 89° \ 00'$ (calc. $90° \ 00'$). The general features of this crystal are shown in figure 43, the smaller details being omitted.

Crystal 7 shows the rare form $q\{015\}$ as a line face giving a very poor reflection, ρ measuring $18° \ 30'$ (calc. $19° \ 01'$). The new forms

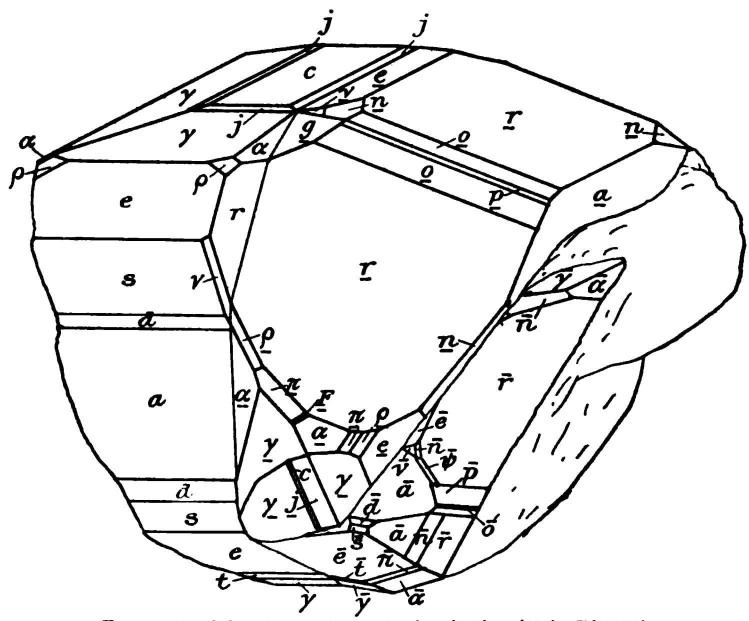


FIGURE 43.—Calomel crystal 6: $g\{160\}$, $\psi\{131\}$, $p\{331\}$, $F\{3.5.11\}$.

$j\{0.1.12\}$, $\varepsilon\{117\}$ and $T\{334\}$ are present. A number of forms vicinal to $\{113\}$ occur, their measurements being shown below:

Measurements of {113} and vicinal forms on crystal 7, calomel.

	ϕ		ρ	
	°	′	°	′
Calculated (113)	**45**	**00**	**39**	**05**
Measured (113)	45	10	39	15
	45	09	39	22
	45	00	39	07
Vicinal forms measured	42	52	39	30
	38	57	40	15
	40	57	38	00

Crystal 10 shows the new forms $j\{0.1.12\}$, $Y\{018\}$, $H\{1.1.24\}$, and also the rare form $q\{015\}$ as a line face giving a poor reflection, measuring $\rho = 18° \ 41'$ (calc. $19° \ 01'$). A part of this crystal showing $H\{1.1.24\}$ is shown in figure 44.

FORM SYSTEM.

The writer has arranged the following table of the forms and coordinate angles of calomel in a form that he thinks is most prac-

tical. The table differs from those given by Goldschmidt in his Winkeltabellen in some features. First, only the ϕ and ρ angles are given, as these are the only values needed to identify a form during the measurements. Second, references are given for each form, unless the form has been observed by at least three independent workers. Third, except for the prism zones, the forms are arranged in increasing values of the angles. The table given by Goldschmidt and Mauritz is used as a basis, the following forms being added to their table for the reasons set forth in the foregoing pages: $\mu\{552\}$, $K\{553\}$, $F\{3.5.11\}$, $j\{0.1.12\}$ (?), and $H\{1.1.24\}$ (?)

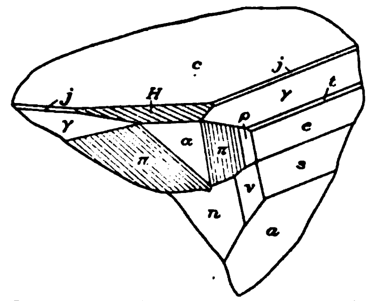


FIGURE 44.—Calomel crystal 10: $H\{1.1.24\}$, $a\{113\}$, $j\{0.1.12\}$.

Forms and coordinate angles for calomel.

[Tetragonal. $c=p_0=1.7232$.]

No.	Letter.	Symbol. Gdt.	Symbol. Miller.	ϕ	ρ	References.
				° ′	° ′	
1	c	0	001	....	0 00	
2	a	0∞	010	0 00	90 00	
3	m	∞	110	45 00	90 00	
4	l	$\infty 2$	120	26 34	90 00	4, 5
5	j (?)	$0\frac{1}{12}$	0.1.12	0 00	8 10	5, 6
6	δ	$0\frac{1}{6}$	016	0 00	16 01	5
7	q	$0\frac{1}{5}$	015	0 00	19 01	2, 6
8	γ	$0\frac{1}{4}$	014	0 00	23 18	
9	z	$0\frac{1}{3}$	013	0 00	29 52	
10	t	$0\frac{1}{2}$	012	0 00	40 40	
11	e	01	011	0 00	59 52	
12	s	02	021	0 00	73 49	
13	d	03	031	0 00	79 03	5, 6
14	v	$\frac{1}{3}\frac{5}{3}$	153	11 19	71 08	
15	ρ	$\frac{1}{5}\frac{3}{5}$	135	18 26	47 27	
16	n	$\frac{1}{2}\frac{3}{2}$	132	18 26	69 50	
17	ψ	13	131	18 26	79 36	
18	π	$\frac{1}{4}\frac{1}{2}$	124	26 34	43 55	
19	F	$\frac{3}{11}\frac{5}{11}$	3.5.11	30 58	42 24	3, 6
20	H (?)	$\frac{1}{24}$	1.1.24	45 00	5 48	6
21	h	$\frac{1}{4}$	114	45 00	31 21	1, 2
22	a	$\frac{1}{3}$	113	45 00	39 05	
23	i	$\frac{1}{2}$	112	45 00	50 37	
24	r	1	111	45 00	67 41	
25	K	$\frac{5}{3}$	553	45 00	76 10	6
26	o	2	221	45 00	78 24	
27	μ	$\frac{5}{2}$	552	45 00	80 40	1, 6
28	p	3	331	45 00	82 12	

1. Traube, Zeitschr. Kryst. Min., vol. 14, 1888, p. 571.
2. Vrba, Zeitschr. Kryst. Min., vol. 15, 1889, p. 455.
3. Websky, Monatsber. K. Akad. Wiss., Berlin, 1877, p. 461.
4. Moses, Am. Jour. Sci., 4th ser., vol. 16, 1903, p. 253.
5. Goldschmidt and Mauritz, Zeitschr. Kryst. Min., vol. 44, 1907-8, p. 393.
6. The present publication.

MERCURY.

Being a liquid, mercury can not show any crystals under ordinary conditions, but the occurrences of mercury shown by these specimens may nevertheless be grouped under two heads:

1. Distinct globules.
2. Mixed with some of the other minerals and forming a sort of stiff paste which may be the "amalgam" referred to in previous papers on these minerals.

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JC Branner

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 406

PRELIMINARY REPORT

ON THE

McKITTRICK-SUNSET OIL REGION

KERN AND SAN LUIS OBISPO COUNTIES

CALIFORNIA

BY

RALPH ARNOLD AND HARRY R. JOHNSON

N

G OFFICE

CONTENTS.

ILLUSTRATIONS.

PRELIMINARY REPORT ON THE McKITTRICK-SUNSET OIL REGION, CALIFORNIA.

By Ralph Arnold and Harry R. Johnson.

INTRODUCTION.

GENERAL FEATURES OF THE REGION.

The region described in this report lies in western Kern and eastern San Luis Obispo counties, Cal., and embraces the northeastern flank of the Diablo and Temblor ranges, and the Carrizo and Elkhorn plains and surrounding mountain flanks. The area shown on the topographic map is a strip 75 miles long and 30 miles wide and includes about 1,800 square miles; the area geologically mapped includes between 1,500 and 1,700 square miles. The region is accessible by rail from the main lines of both the Southern Pacific and the Atchison, Topeka and Santa Fe railroads by branch lines running westward from Bakersfield to McKittrick and southwestward from Bakersfield to Maricopa and Moron. The region includes the proved productive territory of the well-known and important McKittrick, Midway, and Sunset fields, and the less important and as yet undeveloped Devils Den, Temblor, and Carrizo Plain districts. In the three most important fields the oil is believed to have originated largely in the Monterey and Santa Margarita (?) (middle Miocene) formations, and is accumulated in the porous basal portion of the unconformably overlying McKittrick (upper Miocene) formation. The Vaqueros sandstone (lower Miocene) is oil bearing in the Devils Den, Temblor, and Carrizo Plain districts.

The product of the McKittrick field is a dark-colored oil varying from 12.5° to 20° Baumé, with an average of from 15° to 18°. The production of the individual wells varies from 2 to 1,000 barrels, with an average of about 100 barrels. The production of this field was 2,517,951 barrels in 1908.

The product of the Midway field is a black to greenish-brown oil varying in gravity from 11° to 22° Baumé, with an average of 16° to 18° Baumé. The production of the individual wells is from 10

to 2,500 barrels, or possibly more, per day; the average is believed to be 100 barrels or less. The product of the Midway field was 410,393 barrels in 1908.

The Sunset field yields a black oil varying in gravity from 11° to 20° Baumé, most of it best adapted for fuel and road oil. The production of the individual wells is from 4 to 400 barrels per day; the average for the field is about 100 barrels per day. In 1908 the Sunset field produced 1,556,263 barrels of oil.

The oil of these fields is transported largely by tank cars, although a pipe line (that of the Standard Oil Company) taps the McKittrick and Midway districts and two other pipe lines to serve all three fields are now in course of construction. The oil is used largely for fuel, road dressing, and refining for asphalt.

SETTLEMENT.

The earliest mention of the region occurs in some of the annals of the Spanish padres, among whom Garces [a] is a notable example. This zealous worker for the spread of Spanish influence crossed the Temblor or the Mount Pinos Range somewhere in the neighborhood of Sunset, in the spring of 1776, during an exploration for the site of a mission in the Great Valley.

Although the petroleum deposits have long been known, practically all of the development has come within the past twenty years, and most of it during the last ten years. Except locally, the region is not at present valuable for agricultural purposes, and in consequence settlements are few. The population of the region has increased rapidly within the past two years, owing to the rejuvenation of the oil industry, so that at present, while actual figures are not at hand, there are probably over 3,000 people resident in the territory.

PLAN OF THE PRESENT REPORT.

During the last half of 1901 and the first half of 1902 George H. Eldridge, of the United States Geological Survey, made more or less detailed examinations of the various California oil districts, with the expectation of preparing a monograph on the oil resources of the State. On his return from field work he wrote a brief résumé of the results obtained, and this was published.[b] Later he began the preparation of detailed reports on each field, but his lamented death, in June, 1905, cut short this work. In the fall of 1905 the senior author of this bulletin was instructed to complete the work begun by Mr. Eldridge, and by the fall of 1908 detailed reports on all of the oil

[a] Coues, Elliott, On the trail of a Spanish pioneer, vol. 1, pp. 272-280.

[b] Eldridge, G. H., The petroleum fields of California: Contributions to economic geology, 1902: Bull. U. S. Geol. Survey, No. 213, 1903, pp. 306-321. (The part relating particularly to the McKittrick, Midway, and Sunset districts is on pp. 308-310.)

districts in the counties bordering the coast, and also on the Coalinga oil district, immediately north of the region covered by the present report, had been issued.[a]

The summer and fall of 1908 were spent by the writers in making a more or less detailed geologic investigation of the McKittrick, Midway, and Sunset districts, together with a detailed reconnaissance of the rest of the region covered by the present report, which includes what have been called the Devils Den, Lost Hills, Bitterwater, Carneros, and Carrizo Plain districts. The territory in the extreme southwestern part of the region covered by the McKittrick-Sunset map, including the Caliente Range, was not visited, owing to lack of time. In order to make the results of this investigation available as soon as possible, it has been deemed expedient to prepare the following preliminary report. This will be followed later by bulletins containing more elaborate maps, sections, and other illustrations, and chemical analyses and calorific tests of a large number of the oils. The location of the McKittrick-Sunset region and the other oil districts of southern California are shown in figure 1.

For the benefit of those using this and other geologic reports on the California oil fields, it must be stated that these publications are intended to be as thoroughly scientific discussions as possible, and that they assume on the part of the reader a general knowledge of the fundamental facts and conceptions on which any searching study of the composition, mineral deposits, and history of the earth must be based. The reports may be criticised as too technical and as not easily comprehensible by the ordinary reader, but the treatment adopted is the only consistent one for a subject that involves technical knowledge and the use of exact terms. Explanatory discussions have been inserted wherever it seemed possible to do so without making the reports too bulky or diminishing their scientific value. For explanations of the principles of geology or the meaning of terms, the reader is referred to any of the numerous text-books of geology.[b]

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[a] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: Bull. U. S. Geol. Survey No. 309, 1907.

Arnold, Ralph, and Anderson, Robert, Preliminary report on the Santa Maria oil district, Santa Barbara County, Cal.: Bull. U. S. Geol. Survey No. 317, 1907.

Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, Cal.: Bull. U. S. Geol. Survey No. 321, 1907.

Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal.: Bull. U. S. Geol. Survey No. 322, 1908.

Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga oil district, Fresno and Kings counties, Cal.: Bull. U. S. Geol. Survey No. 357, 1908.

Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga oil district, Fresno and Kings counties, Cal.: Bull. U. S. Geol. Survey No. 398, 1910.

[b] Any of the following, besides various others, will be found useful: Dana, Text-book of geology; Le Conte, Elements of geology; Chamberlin and Salisbury, Geology (3 parts); Geikie, Text-book of geology.

CONDITIONS LIMITING ACCURACY OF MAPS.

In using the preliminary geologic map which accompanies this report, the following facts must be kept constantly in mind:

First, the map is based upon a reconnaissance which permitted to the topographers to whom the mapping was intrusted a certain latitude in the degree of accuracy required. The exactness of a detailed special map is therefore not to be expected either in contouring or in location of cultural features.

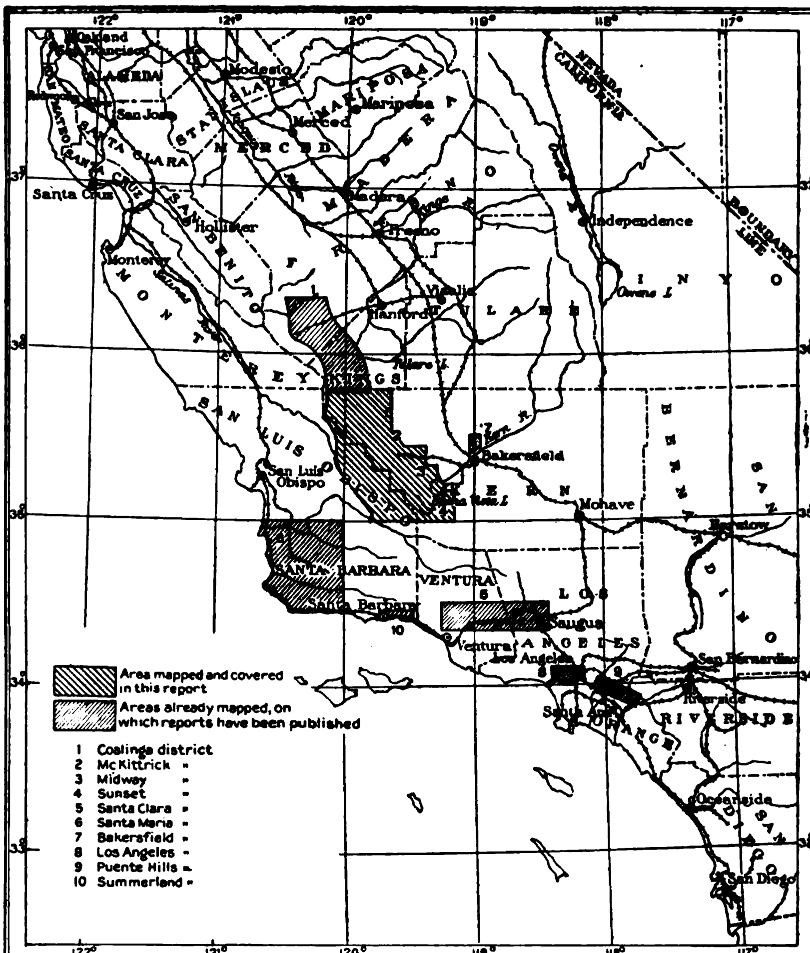

FIGURE 1.—Index map of a part of California, showing position of McKittrick-Sunset region.

Second, where contacts between various formations, or structural lines, are clearly defined in the field, they have been located with as close an approach to accuracy as the scale of the map will allow.

At some places conditions are so indefinite that much less accuracy in drawing contacts, etc., has been possible, and symbols indicative of indefinite contacts, faults, and folds have been necessary. Throughout the whole region studied geologic features have been indicated almost wholly with reference to contouring, drainage, houses, and roads.

Third, the factor that most limits the proper use of the geologic map is the inaccuracy of many of the land lines in this region. Many of the surveys were originally poor; few of the original corners either of sections or townships can now be found; and in some portions of the region as many as five additional surveys, none of which tie, have been made in private, and usually abortive, efforts to locate property lines correctly. It has therefore been impossible everywhere upon the accompanying map to correctly delineate section and township lines with reference to contouring, drainage, houses, and roads, and consequently with reference to geologic features. Since the classification of the region into mineral and nonmineral land must be referred to sections and townships, although based upon geologic evidence, an element of great uncertainty is introduced; this must be allowed for in any consideration of the classification. These inconsistencies can be adjusted only by a resurvey by the United States Land Office of the region involved.

PREVIOUS KNOWLEDGE OF THE REGION.

Reference to the geology and oil resources of the McKittrick-Sunset region is made more particularly in the following publications, besides the Pacific Railroad Reports (1856, etc.), and the Whitney State Survey Reports (1864, etc.):

1894. WATTS, W. L. The gas and petroleum yielding formations of the central valley of California. Bull. California State Min. Bur. No. 3, 100 pp., maps, plates, and figures. Sacramento.

Notes on the topography, geology, and oil resources of the Sunset district will be found on pp. 22–37, and on the McKittrick district (called the Buena Vista district in Watts's report) on pp. 41–53; some analyses of water from the region are on pp. 90 and 91.

1900. WATTS, W. L. Oil and gas yielding formations of California. Bull. California State Min. Bur. No. 19, 236 pp., maps, plates, and figures. Sacramento.

Additional notes to those given in his former report will be found as follows: Geologic sketch of San Joaquin Valley, pp. 106–109; Sunset district, pp. 117–125; McKittrick district, pp. 125–131; Devils Den district, pp. 131 and 132.

1904. COOPER, H. N. Chemical analyses of California petroleum. Bull. California State Min. Bur. No. 31 (also inserted as appendix in Bull. No. 32). Sacramento.

Analyses of oil from the McKittrick, Sunset, and Temblor districts are given in this table.

1904. PRUTZMAN, PAUL W. Production and uses of petroleum in California. Bull. California State Min. Bur. No. 32, 230 pp., maps, plates, figures, and tables. Sacramento.

Maps of the various districts and analyses and notes concerning the physical and chemical properties of the oils, their uses, methods of refining, and other useful data are given in this bulletin.

1905. ANDERSON, FRANK M. A stratigraphic study in the Mount Diablo Range of California. Proc. California Acad. Sci., 3d ser., Geology, vol. 2, pp. 156–248, pls. 13 to 35, 1 map. San Francisco.

This paper includes a brief discussion of the geology and paleontology of the region along the southwestern side of the San Joaquin Valley, including the region from Devils Den to Sunset, together with descriptions and illustrations of many of the fossils found in the Tertiary formations.

1908. ANDERSON, FRANK M. A further stratigraphic study in the Mount Diablo Range of California. Proc. California Acad. Sci., 4th ser., vol. 3, pp. 1–40. San Francisco.

In this paper Mr. Anderson gives a résumé of his former one and makes some corrections regarding the age of certain of the formations necessitated by a further study of the regions.

1910. ARNOLD, RALPH, and ANDERSON, ROBERT. Geology and oil resources of the Coalinga district, Fresno and Kings counties, Cal. Bull. U. S. Geol. Survey No. 398. 354 pp., maps, plates, figures, and tables.

This report includes a discussion of the geology and oil resources of the region immediately adjacent on the north to that covered by the present report. Many of the discussions apply to the McKittrick-Sunset region.

ACKNOWLEDGMENTS.

The writers wish to acknowledge their indebtedness to the late George H. Eldridge for notes collected by him during his examination of the region in 1901 and 1902. These notes were taken at a time when a considerable amount of information concerning the early development work in the districts was available. Many of the data concerning the wells put down in these early days have since been destroyed, and but for Mr. Eldridge's notes a considerable part of the value of the present report would have been lost. Acknowledgment is also due to other previous workers in the region, among whom are W. L. Watts, Frank M. Anderson, and Robert Anderson.

The value and accuracy of a report like the present one, including as it does the discussion of the geology of developed territory, depends largely upon the amount and accuracy of the well data available for use in its preparation. Certain facts may be gleaned from a critical examination of the surface outcrops in any field, and many helpful conclusions may be deduced from a study of the facts thus obtained. A comparison of the conditions in a given territory with those in other better-known fields may also be of great assistance; but for furnishing definite information regarding the occurrence of the oil in any particular area there is just one instrument that may be relied upon, and that is the drill.

From the drilling of wells in the region under discussion during the last sixteen years a large body of useful data concerning the under-

ground conditions has been accumulated, and whatever accuracy and value there is in the underground contour maps and in the statements concerning the geology of the wells in this report is due almost entirely to the generosity of the operators in supplying the information. The writers therefore wish to acknowledge their indebtedness to the officers, managers, and other operators of the different oil companies for their hearty cooperation and support. Thanks are due more particularly to Messrs. W. R. Hamilton, P. A. Williams, H. S. Williams, F. C. Ripley, W. W. Orcutt, W. B. Moore, J. M. Atwell, H. G. Ball, Martin Barber, Orlando Barton, A. H. Butler, H. C. Mosher, Ed. S. Mosher, Walter Snook, W. E. White, Frank M. Anderson, E. H. Andrews, R. L. Atkins, S. G. Atkinson, W. T. Baldwin, Arthur F. L. Bell, R. P. Benedict, C. J. Berry, R. W. Bess, Bernard Bienenfeld, H. L. Black, E. J. Boust, William Brown, Charles F. Burks, E. D. Burge, A. B. Canfield, Clayton I. Chandler, C. L. Cole, J. H. Crafts, L. Creason, Angus J. Crites, Charles Dickinson, R. E. Diggins, the late E. Erickson, Michel Erume, D. R. Evinger, R. N. Ferguson, Mrs. A. W. Gilfillan, R. E. Graham, Henry A. Greene, S. A. Guiberson, jr., H. D. Guthrey, M. L. Harding, C. J. Harvey, R. L. Heber, W. H. Hudgins, W. B. Isaacs, D. A. Jackson, F. L. Keller, J. P. Kerr, G. T. Kincaid, L. J. King, K. King, David Kinsey, J. E. Koeberle, S. G. Lamb, B. F. Levet, A. L. Linneman, M. E. Lombardi, Ed. N. Moore, F. L. Matson, J. A. McClurg, jr., W. G. McCutcheon, J. C. McDonald, J. J. McLimans, D. E. Martin, E. J. Miley, Irving Miller, T. H. Miner, C. J. Murphy, G. R. Neill, John H. Osgood, W. K. Osmer, G. W. Pickle, A. E. Preston, J. E. Prether, George Quarré, S. D. Rankin, G. A. Reynolds, J. A. Reynolds, W. D. Roberts, L. A. Rose, W. J. Schultz, F. N. Scofield, C. V. Scott, I. E. Segur, J. J. Shupe, H. H. Smith, James M. Smith, R. M. Smith, M. A. Spellacy, Martin J. Spellacy, Timothy Spellacy, G. E. Squires, C. W. St. Louis, B. K. Stroud, Richard Syke, S. G. Tryon, T. O. Turner, F. F. Weed, T. J. Whaley, H. G. Whittikin, Claude Wilson, and many others who have contributed in one way or another to the value of the report.

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In a country where even the bare necessities of existence are often hard to obtain one usually finds the truest hospitality. The writers therefore take pleasure in extending thanks to the following, in addition to many of those mentioned above, who extended hospitalities or in other ways facilitated the field work: Warren Rogers, Orris Castell, Robert Potter, W. M. Cook, O. H. Tetzlaff, Edward A. Connors, Mrs. Ed. Still, P. D. Cash, John L. Aramburu, A. E. Gordon, Maddux Brothers, Joseph E. Orchard, and E. E. Morgan.

GEOGRAPHY AND TOPOGRAPHY.

LOCATION.

The country mapped and discussed in this report as the McKittrick-Sunset oil region lies within or along the northeastern edge of the Coast Ranges of California adjacent to the great interior San Joaquin Valley, and comprises the southernmost part of the Diablo Range, the Temblor Range, the Buena Vista and Elk hills, the Caliente Range, and the Carrizo Plain. This region is included between 119° 10′ to 120° 10′ west longitude and 35° to 35° 50′ north latitude. Roughly, this tract of land, about 75 miles long and 30 miles wide, has an area of about 1,800 square miles. Reference to the key map (fig. 1) will show the position of the region with respect to other oil-producing districts of the State.

The developed oil territory commonly referred to as the McKittrick, Midway, Sunset, Temblor, and Devils Den districts lies along the northeastern flank of the Temblor and Diablo ranges, while the Carrizo Plain district occupies the southwestern flank of the Temblor Range adjacent to the Carrizo Plain. The post-offices Simmler, in San Luis Obispo County, and Dudley, Annette, McKittrick, Taft, Maricopa, and Midland, in Kern County, lie within or just outside of the region; the towns and railroad stations McKittrick, Moron, (post-office, Taft) Monarch (post-office, Maricopa), Midoil (post-office, Midland), Fellows or Siding No. 4 (post-office, Midland), and Hazelton (post-office, Maricopa), are also within its borders. A railroad line connects McKittrick with the Southern Pacific and the Atchison, Topeka and Santa Fe railroads at Bakersfield, and another line connects Fellows, Midoil, Moron, Monarch, and Hazelton with the same roads also at Bakersfield. Wagon roads enter the region from Coalinga and Lemoore on the north by way of the Kettleman and Antelope plains; from the Salinas Valley country on the west by Cottonwood Pass, by Polonio Pass and the Antelope Valley, by Palo Prieto Pass and Bitterwater Valley, and by way of La Panza, San Juan River, and Carrizo Plain; from the San Joaquin Valley on the east by way of the Antelope Plain at the south end of the Lost Hills, by way of Lokern north of the Elk Hills, and by routes both north and south of Buena Vista Lake; and from the mountains on the south by way of Maricopa Valley.

DESCRIPTION OF PLACE NAMES.

It is important that the names of the various places and features used in this report should be clearly defined before the topographic and geologic discussion is begun. The region is one in which little detailed investigation has been made, and most of the natural features are unnamed, while to many others names are indefinitely applied. The following definitions of names that have been newly applied and

of names whose application has been made more definite have been submitted to the United States Geographic Board and have been approved and made permanent by that body. Most of these names appear on the map (Pl. I). Township and range numbers south and east refer to the Mount Diablo base and meridian. Numbers north and west refer to the San Bernardino base and meridian.

Aido Spring.—This name is used for the sulphur spring in the N. ½ sec. 35, T. 25 S., R. 17 E.

Alamo Solo Springs.—The well-established name for springs at a lone cottonwood near the center of sec. 2, T. 25 S., R. 18 E.; means "lone cottonwood" springs.

Antelope Hills.—This name is proposed to include the group of low hills lying in the SW. ¼ T. 27 S., R. 20 E., and the N. ½ T. 28 S., R. 20 E. These hills are a range for the few wild antelope left in this region.

Aramburu Canyon.—This is the locally accepted name for a canyon lying in sec. 13, T. 30 S., R. 20 E. It is named for a Portuguese settler, John L. Aramburu, residing at the mouth of the canyon.

Barril Valley.—Lies in about the center of T. 26 S., R. 17 E., and opens into Franciscan Creek (to be described later).

Barton's.—The name applied to a group of buildings, including the cabin of Orlando D. Barton, an old settler, in the N. ½ sec. 23, T. 25 S., R. 18 E.

Barton Hills.—An irregular group of hills lying almost entirely in the S. ½ T. 25 S., R. 18 E. Named for the gentleman mentioned in the last paragraph, who has made this region his study for many years.

Bitter Creek.—An intermittent stream heading in the SW. corner of T. 11 N., R. 24 W., and flowing diagonally northeast across the township. The quality of the water gives the name to this creek.

Bitterwater Creek.—A long, intermittent stream heading in the southeast corner of T. 28 S., R. 18 E., flowing due northwest across the township, thence turning northeast and emptying into the San Joaquin Valley in the NW. ¼ T. 27 S., R. 19 E. This name also is derived from the quality of the creek water.

Bitterwater Valley.—The valley of Bitterwater Creek from the southwest corner of T. 27 S., R. 18 E., to its debouchment.

Buena Vista Hills.—This name is proposed for the low ridge extending from the NE. ¼ T. 32 S., R. 24 E., northwestward to the northwest corner of T. 31 S., R. 23 E.

Buena Vista Valley.—The gravel-filled depression lying between the two ranges comprising Buena Vista Hills and the Elk Hills. The names of this valley and of the range to the south are proposed because of their proximity to Buena Vista Lake.

Carneros Spring.—The only available source of drinking water along the road between Dudley and McKittrick; long known variously as Canary, Canaris, Carnaros, and Carnaris. The origin of the name is definitely established now as referring to a sheep camp which formerly existed here, and the spelling "Carneros" is preferred. The spring lies in sec. 5, T. 29 S., R. 20 E.

Carneros Canyon.—The name long used for the well-marked canyon heading in the NE. ¼ T. 29 S., R. 19 E., and trending northeastward into sec. 20, T. 28 S., R. 20 E., where it enters the San Joaquin Valley.

Carnaza Creek.—The name applied to a creek which flows southwestward across the E. ½ T. 28 S., R. 17 E., and into which flows Carnaza Spring. These names are of local application.

Cottonwood Creek.—An intermittent stream flowing into McLure Valley from the northern part of T. 25 S., R. 17 E.

Cottonwood Pass.—The pass between the McLure and Cholame valleys at the head of Cottonwood Creek.

Crocker Flat.—The name proposed for an area lying mostly in secs. 19 and 30, T. 31 S., R. 22 E.

Devils Den.—The name applied to the vicinity of a peculiar rock cropping in sec. 20, T. 25 S., R. 18 E.

Devilwater Creek.—The name of an intermittent stream flowing northeastward through the N. ½ T. 28 S., R. 19 E. Origin probably traceable to the unsavory character of the water.

Elk Hills.—The name proposed for the low range almost wholly included in T. 30 S., R. 23 E.; T. 30 S., R. 24 E.; T. 31 S., R. 23 E.; and T. 31 S., R. 24 E. The few remaining elk in this region are said to range in these hills.

Elkhorn Hills.—The name proposed for a group of hills extending northwestward across T. 11 N., R. 25 W.

Elkhorn Scarp.—The name proposed for the terrace-like escarpment extending from the southeast corner of T. 11 N., R. 25 W., northwestward across T. 12 N., R. 26 W., T. 32 S., R. 22 E., and T. 32 S., R. 21 E., into the SW. ¼ T. 31 S., R. 21 E. This feature is purely structural, following the great San Andreas fault or rift, and hence the application of the term "scarp."

Emigrant Hill.—The name locally applied to an isolated point in sec. 24, T. 25 S., R. 18 E. This hill is said to have been a landmark for the traveler in this region in the earlier days.

Franciscan Creek.—The name proposed for the intermittent stream flowing northeastward across the SE. ¼ T. 26 S., R. 17 E. Rocks of the Franciscan formation exist along the stream.

Frazer Valley.—The name proposed for a partly inclosed depression in the hills south of Frazer Spring and lying mostly in secs. 2 and 3, T. 30 S., R. 21 E.

Gould Hills.—The name proposed, after a pioneer operator, for hills north of the Temblor Valley and lying in the northern part of T. 29 S., R. 20 and 21 E.

Los Yeguas Creek.—The name applied locally to the stream heading in sec. 30, T. 28 S., R. 19 E., and flowing southwestward into Bitterwater Creek. Formerly many brood mares were pastured about the head of this stream. The name means "the mares."

Maricopa Valley.—The name proposed for the partly structural depression through which Bitter Creek flows. This valley lies in the central portion of T. 11 N., R. 24 W.

McKittrick Summit.—The name proposed for the 4,323-foot point in the N. ½ sec. 30, T. 30 S., R. 21 E.

McKittrick Valley.—The name proposed for the depression which extends northwestward through T. 30 S., R. 22 E., and in which lies the town of McKittrick.

McGovern Gap.—The name locally applied to a natural gateway in the hills in sec. 4, T. 26 S., R. 17 E. A settler named McGovern resides near this point.

Media Agua Creek.—The name applied locally to a stream flowing approximately north through the central part of T. 28 S., R. 19 E.; means "middle water" creek (halfway between Carneros Spring and a well at Point of Rocks).

Midway Peak.—A 3,651-foot point in sec. 4, T. 32 S., R. 22 E. Named from proximity to Midway oil field.

Midway Valley.—An alluvial depression extending from the south-central portion of T. 32 S., R. 24 E., northwestward into the N. ½ T. 31 S., R. 22 E. It lies between Buena Vista Hills and the main Temblor Range, and is named for its proximity to the Midway oil field.

Miller Flats.—The name proposed for the rolling uplands lying mostly within the NE. ¼ T. 27 S., R. 17 E. Named for James Miller, an old settler in this region.

Orchard Peak.—The name proposed for the summit in sec. 22, T. 25 S., R. 17 E. Named for Joseph E. Orchard, an old resident of the McLure Valley.

Palo Prieto Pass.—A long-standing name for the narrow trough-like pass extending from the middle of T. 27 S., R. 17 E., northwestward into T. 26 S., R. 16 E.

Polonio Pass.—The name applied to the low pass at the head of Antelope Valley, lying mostly within T. 25 S., R. 17 E.

Panorama Hills.—The name proposed for the low range extending from the northeast corner of T. 32 S., R. 21 E., northwestward to sec. 7, T. 31 S., R. 21 E.

Panorama Point.—A conspicuous hill in sec. 34, T. 31 S., R. 21 E. This name has been used for some years by E. W. White, a settler in the region.

Pyramid Hills.—This range of hills is more accurately defined south of Dagany Gap, as including the ridges which extend southeastward from sec. 2, T. 25 S., R. 18 E., to and including Emigrant Hill.

Raven Pass.—The local name for the low pass in sec. 30, T. 26 S., R. 18 E.

Salt Spring.—The well-known local name of the saline tar spring on the north line of sec. 25, T. 25 S., R. 18 E.

Sandiego Joe's.—The name of a ranch in sec. 8, T. 30 S., R. 20 E., in Sandiego Canyon.

Santos Creek.—A name derived from that of an old settler, Joe Santos, and applied locally to a short stream flowing northeastward through the SE. ¼ T. 28 S., R. 19 E., and joining Carneros Creek.

Santa Maria Valley.—The local name of a depression extending northwestward through the central part of T. 30 S., R. 21 E.

Sawtooth Ridge.—The name proposed for a ridge lying mostly in sec. 1, T. 26 S., R. 17 E. This name is applied because of the jagged topography there.

Shale Hills.—The name proposed for the group of hills lying in the NE. ¼ T. 27 S., R. 18 E., and that portion of the S. ½ T. 26 S., R. 18 E., which lies northeast of Raven Pass.

Shale Point.—This name is proposed for the low ridge in the NE. ¼ sec. 7, T. 27 S., R. 19 E.

Spellacy Hill.—The name proposed for the rather isolated hill lying mostly in secs. 22, 23, 24, 25, and 26, of T. 32 S., R. 23 E. Spellacy Brothers, of Los Angeles, were among the earlier oil investors prominently connected with the development of the territory in this vicinity.

Syncline Hill.—The name proposed for a prominent structural feature lying in the SE. ¼ T. 29 S., R. 17 E.

Vishnu well.—The name applied to an oil well in sec. 22, T. 32 S., R. 22 E.

GENERAL TOPOGRAPHIC FEATURES.

Although there is great diversity in the relief of the region, the arid climate in this latitude exerts a definite control over the topography, so that original structural features, the results of mountain-building activities, have been remarkably preserved throughout. Drainage lines are usually sharply incised and the uplands are often marked by steep slopes. The lowlands are characterized by the broad, gently sloping, gravelly fans resulting from the intermittent precipitation of an arid country.

Diablo Range.—The southern extremity of the chain of ridges of the Diablo Range, so important topographically in the Coalinga

district, terminates in the north end of the present region as a rugged, somber spur reaching an elevation of about 3,000 feet. Associated with the Diablo Range are the much lower structural ridges of the Pyramid and Kettleman hills which lie to the east.

Temblor Range.—This range, which is the dominating feature of the region, lies at its north end en échelon with the Diablo Range and coalesces with the Mount Pinos group of mountains toward the south. It has a true northwest and southeast direction, and preserves a uniform width of about 7 miles and a broadly even summit line, which reaches its greatest elevation of 4,300 feet west of McKittrick. The southwest slope of the range is steep and through most of its length sharply demarked from the flat Carrizo Plain, while the northeast slope descends in a series of irregular tiers of hills, the lowest of which merge gently into the fans of the San Joaquin Valley.

Buena Vista and Elk Hills.—This group of hills occupies a roughly elliptical area northeast of the Temblor Range, between McKittrick and Buena Vista Lake. It includes two ranges elongated in a direction somewhat north of west and separated by a gravel-filled depression. These hills reach an elevation of about 1,500 feet. Like all of the lower relief in the region, they are barren of all except low-growing vegetation—grasses and sagebrush.

Carrizo Plain.—This great inclosed depression, lying along the southwestern side of the Temblor Range and between it and the Caliente Range, has a length of about 50 miles and a width at its lowest portion of about 7 miles, but gradually tapers toward the southeast to less than one-third this width at a point several miles southwest of Maricopa. The plain has an elevation of 2,000 to 2,500 feet.

San Joaquin Valley.—A portion of the margin of this great valley lies within the region under discussion. It is an area of coalescent alluvial fans which slope gently downward toward the northeast from the lower hills of the Temblor and Diablo ranges. At several points are reentrants of the valley, notably at Antelope Valley, which separates the Temblor and Diablo ranges, and at Buena Vista and Midway valleys. The western margin of the San Joaquin Valley has an elevation of about 1,000 feet.

LAND CLASSIFICATION.

The following areas within the McKittrick-Sunset oil region have been classified as mineral lands and such of these as yet belong to the Government have been withdrawn from all kinds of entry, "pending consideration of the question of legislation upon the subject, unless it be shown by reclassification or sufficient evidence that any particular tract or tracts thereof do not in fact contain oil." Lands classified as mineral include all those lying between the

surface outcrop of the bottom of the lowest oil-bearing formation (Vaqueros) and a line marking the limits of the area in which the uppermost productive oil zone can be reached by a well 5,000 feet or less deep. This margin is indicated on the geologic map accompanying this report by a heavy blue line.

Lands classified as oil lands.

[Mount Diablo base and meridian.]

T. 25 S., R. 18 E.:
- Sec. 1: W. ½ and SE. ¼ of NW. ¼, SW. ¼, SW. ¼ of SE. ¼.
- Sec. 2: All.
- Sec. 3: E. ½.
- Sec. 8: S. ½ of SE. ¼.
- Sec. 9: S. ½ of S. ½.
- Sec. 10: E. ½ of NE. ¼, S. ½ of SW. ¼, SW. ¼ and E. ½ of SE. ¼.
- Sec. 11: All.
- Sec. 12: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
- Secs. 13, 14, 15, and 16: All.
- Sec. 17: E. ½, E. ½ of NW. ¼.
- Sec. 20: NE. ¼ of NE. ¼.
- Sec. 21: N. ½.
- Sec. 22: N. ½, NE. ¼ of SW. ¼, NW. ¼ of SE. ¼.
- Sec. 23: N. ½, N. ½ of S. ½.
- Sec. 24: All.
- Sec. 25: E. ½, NE. ¼ of NW. ¼.
- Sec. 36: NE. ¼, E. ½ of NW. ¼, N. ½ and SE. ¼ of SE. ¼.

T. 25 S., R. 19 E.:
- Secs. 1 and 2: All.
- Sec. 3: E. ½, NW. ¼, N. ½ and SE. ¼ of SW. ¼.
- Sec. 4: NE. ¼ of NE. ¼.
- Sec. 7: SW. ¼ of SW. ¼.
- Sec. 10: NE. ¼.
- Sec. 11: E. ½, NW. ¼, N. ½ and SE. ¼ of SW. ¼.
- Secs. 12 and 13: All.
- Sec. 14: NE. ¼, NE. ¼ of NW. ¼, NE. ¼ of SE. ¼.
- Sec. 18: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ of SE. ¼.
- Sec. 19: All.
- Sec. 20: SW. ¼ of NW. ¼, W. ½ and SE. ¼ of SW. ¼.
- Sec. 24: NE. ¼, E. ½ of NW. ¼, E. ½ and NW. ¼ of SE. ¼.
- Sec. 25: NE. ¼ of NE. ¼.
- Sec. 29: W. ½.
- Secs. 30 and 31: All.
- Sec. 32: W. ½ and SE. ¼ of SE. ¼, W. ½.

T. 25 S., R. 20 E.:
- Sec. 6: SW. ¼ of NW. ¼, SW. ¼, SW. ¼ of SE. ¼.
- Sec. 7: All.
- Sec. 8: SW. ¼ of NW. ¼, W. ½ and SE. ¼ of SW. ¼.
- Sec. 17: W. ½ of NE. ¼, W. ½, SE. ¼.
- Secs. 18, 19, and 20: All.
- Sec. 21: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ and SE. ¼ of SE. ¼.
- Sec. 27: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ of SE. ¼.
- Secs. 28 and 29: All.
- Sec. 30: E. ½, NW. ¼, E. ½ of SW. ¼.
- Sec. 31: E. ½ of NE. ¼.

T. 25 S., R 20 E.—Continued.
Sec. 32: E. ½, NW. ¼, E. ½ and NW. ¼ of SW. ¼.
Secs. 33 and 34: All.
Sec. 35: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ and SE. ¼ of SE. ¼.
T. 26 S., R. 19 E.:
Sec. 4: SW. ¼ of NW. ¼, SW. ¼.
Sec. 5: All.
Sec. 6: NE. ¼, E. ½ and NW. ¼ of NW. ¼, E. ½ and NW. ¼ of SE. ¼.
Sec. 8: E. ½, NW. ¼, NE. ¼ of SW. ¼.
Sec. 9: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
Sec. 16: N. ½.
Sec. 17: NE. ¼ of NE. ¼.
T. 26 S., R. 20 E.:
Sec. 1: S. ½ of NW. ¼, SW. ¼, SW. ¼ of SE. ¼.
Secs. 2 and 3: All.
Sec. 4: E. ½, NW. ¼, E. ½ and NW. ¼ of SW. ¼.
Sec. 5: E. ½ and NW. ¼ of NE. ¼.
Sec. 9: E. ½ and NW. ¼ of NE. ¼.
Secs. 10 to 14, inclusive: All.
Sec. 15: NE. ¼, NE. ¼ of NW. ¼, NE. ¼ of SE. ¼.
Sec. 23: NE. ¼, NE. ¼ of NW. ¼, NE. ¼ of SE. ¼.
Sec. 24: All.
Sec. 25: NE. ¼, NE. ¼ of NW. ¼.
T. 26 S., R. 21 E.:
Sec 7: SW. ¼ of NW. ¼, W. ½ and SE. ¼ of SW. ¼.
Sec. 18: SW. ¼ of NE. ¼, W. ½, SE. ¼.
Sec. 19: All.
Sec. 20: W. ½ of NW. ¼, SW. ¼, SW. ¼ of SE. ¼.
Sec. 29: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
Sec. 30: E. ½, NW. ¼, E. ½ and NW. ¼ of SW. ¼
Sec. 31: NE. ¼ of NE. ¼.
Sec. 32: N. ½.
T. 28 S., R. 19 E.:
Sec. 12: SE. ¼ of SE. ¼.
Sec. 13: E. ½ of NE. ¼, SE. ¼.
Sec. 24: E. ½.
Sec. 25: NE. ¼, NE. ¼ of SE. ¼.
T. 28 S., R. 20 E.:
Sec. 7: S. ½ of S. ½.
Sec. 8: S. ½ of SW. ¼.
Sec. 15: SW. ¼, S. ½ of SE. ¼.
Sec. 16: S. ½ of NE. ¼, W. ½, SE. ¼.
Secs. 17 to 22, inclusive: All.
Sec. 23: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ and SE. ¼ of SE. ¼.
Sec. 25: W. ½ of NW. ¼, SW. ¼.
Secs. 26 to 30, inclusive: All.
Sec. 31: NE. ¼, E. ½ of NW. ¼, N. ½ of SE. ¼.
Secs. 32 to 35, inclusive: All.
Sec. 36: W. ½ of NE. ¼, W. ½, SE. ¼.
T. 29 S., R. 19 E.:
Sec. 23: SE. ¼, SE. ¼ of SW. ¼.
Sec. 24: SW. ¼, W. ½ and SE. ¼ of SE. ¼.
Sec. 25: All.
Sec. 26: E. ½, E. ½ of NW. ¼.

T. 29 S., R. 19 E.—Continued.
Sec. 35: NE. $\frac{1}{4}$ of NE. $\frac{1}{4}$.
Sec. 36: N. $\frac{1}{2}$, NW. $\frac{1}{4}$, E. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
T. 29 S., R. 20 E.:
Secs. 1, 2, and 3: All.
Sec. 4: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 9: NE. $\frac{1}{4}$, E. $\frac{1}{2}$ of NW. $\frac{1}{4}$, E. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Secs. 10, 11, and 12: All.
Sec. 13: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 14: N. $\frac{1}{2}$, W. $\frac{1}{2}$ and NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$, N. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 15: NE. $\frac{1}{4}$, E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$, NW. $\frac{1}{4}$ and E. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 24: E. $\frac{1}{2}$, SW. $\frac{1}{4}$ and E. $\frac{1}{2}$ of NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 25: E. $\frac{1}{2}$, E. $\frac{1}{2}$ and SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 26: SW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 27: SW. $\frac{1}{4}$, W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Sec. 28: S. $\frac{1}{2}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
Sec. 29: S. $\frac{1}{2}$ of NE. $\frac{1}{4}$, W. $\frac{1}{2}$, SE. $\frac{1}{4}$.
Secs. 30 to 36, inclusive: All.
T. 29 S., R. 21 E.:
Sec. 4: SW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Sec. 5: S. $\frac{1}{2}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
Sec. 6: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of NE. $\frac{1}{4}$, W. $\frac{1}{2}$, SE. $\frac{1}{4}$.
Secs. 7, 8, and 9: All.
Sec. 10: SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 15: W. $\frac{1}{2}$ of NE. $\frac{1}{4}$, W. $\frac{1}{2}$, W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Secs. 16 to 22, inclusive: All.
Sec. 23: SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, S. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 24: S. $\frac{1}{2}$ of SW. $\frac{1}{4}$.
Secs. 25 to 36, inclusive: All.
T. 29 S., R. 22 E.:
Sec. 29: SW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 30: S. $\frac{1}{2}$ of NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Sec. 31: All.
Sec. 32: SW. $\frac{1}{4}$ of NE. $\frac{1}{4}$, W. $\frac{1}{2}$, W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
T. 29 S., R. 23 E.:
Sec. 31: S. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 32: S. $\frac{1}{2}$ of NE. $\frac{1}{4}$, SE. $\frac{1}{4}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
Sec. 33: All.
Sec. 34: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of NE. $\frac{1}{4}$, W. $\frac{1}{2}$, SE. $\frac{1}{4}$.
Sec. 35: S. $\frac{1}{2}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
Sec. 36: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
T. 30 S., R. 20 E.:
Secs. 1 to 5, inclusive: All.
Sec. 6: NE. $\frac{1}{4}$, NW. $\frac{1}{4}$ and E. $\frac{1}{2}$ of NE. $\frac{1}{4}$, NW. $\frac{1}{4}$ and E. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 8: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Secs. 9 to 16, inclusive: All.
Sec. 17: NW. $\frac{1}{4}$ and E. $\frac{1}{2}$ of NE. $\frac{1}{4}$, E. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 21: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, NW. $\frac{1}{4}$ and E. $\frac{1}{2}$ of SW. $\frac{1}{4}$.
Secs. 22 to 26, inclusive: All.
Sec. 27: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 28: E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of NE. $\frac{1}{4}$.
Sec. 34: N. $\frac{1}{2}$ of NE. $\frac{1}{4}$.
Sec. 35: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 36: All.

T. 30 S., R. 21 E.: All.
T. 30 S., R. 22 E.:
Sec. 1: S. ½ of NE. ¼, S. ½.
Sec. 2: S. ½ of SW. ¼, SE. ¼.
Sec. 3: SW. ¼, S. ½ of SE. ¼.
Sec. 4: SW. ¼ of NE. ¼, W. ½ and SE. ¼ of NW. ¼, S. ½.
Secs. 5 to 36 inclusive: All.
T. 30 S., R. 23 E.: All.
T. 30 S., R. 24 E.:
Sec. 6: S. ½ of NW. ¼, S. ½.
Sec. 7: All.
Sec. 8: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
Sec. 9: SW. ¼ of NW. ¼, SW. ¼, S. ½ of SE. ¼.
Sec. 14: SW. ¼ of SW. ¼.
Sec. 15: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ and SE. ¼ of SE. ¼.
Secs. 16 to 22 inclusive: All.
Sec. 23: S. ½ of NE. ¼, W. ½, SE. ¼.
Sec. 24: SW. ¼, S. ½ of SE. ¼.
Secs. 25 to 36 inclusive: All.
T. 30 S., R. 25 E.:
Sec. 29: W. ½ and SE. ¼ of SW. ¼.
Sec. 30: SW. ¼ of NE. ¼, W. ½, SE. ¼.
Sec. 31: All.
Sec. 32: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
Sec. 33: W. ½ and SE. ¼ of SW. ¼.
T. 31 S., R. 20 E.:
Sec. 1: All.
Sec. 2: NW. ¼ and E. ½ of NE. ¼, NE. ¼ of SE. ¼.
Sec. 12: All.
Sec. 13: NE. ¼, E. ½ of NW. ¼, NW. ¼ and E. ½ of SE. ¼.
Sec. 24: NE. ¼ of NE. ¼.
T. 31 S., R. 21 E.:
Secs. 1 to 13 inclusive.
Sec. 14: E. ½, NW. ¼, E. ½ and NW. ¼ of SW. ¼.
Sec. 15: E. ½ and NW. ¼ of NE. ¼, SW. ¼ of NW. ¼, SW. ¼.
Sec. 16: NE. ¼, E. ½ and NW. ¼ of NW. ¼, SW. ¼ of SW. ¼.
Secs. 17 and 18: All.
Sec. 19: NW. ¼, NE. ¼ of SW. ¼, E. ½.
Secs. 20 to 28 inclusive: All.
Sec. 29: E. ½, NW. ¼, NE. ¼ of SW. ¼.
Sec. 30: NE. ¼ of NE. ¼.
Sec. 32: NE. ¼ of NE. ¼.
Sec. 33: E. ½, NW. ¼, NE. ¼ of SW. ¼.
Secs. 34, 35, and 36: All.
T. 31 S., R. 22 E.: All.
T. 31 S., R. 23 E.: All.
T. 31 S., R. 24 E.: All.
T. 31 S., R. 25 E.:
Sec. 3: SW. ¼ of SW. ¼.
Sec. 4: W. ½ and SE. ¼ of NE. ¼, NW. ¼, S. ½.
Secs. 5 to 9 inclusive: All.
Sec. 10: W. ½ of W. ½.
Sec. 15: NW. ¼ of NW. ¼.
Sec. 16: NE. ¼, W. ½, NW. ¼ of SE. ¼.

T. 31 S., R. 25 E.—Continued.
Secs. 17 and 18: All.
Sec. 19: NE. $\frac{1}{4}$, W. $\frac{1}{2}$, W. $\frac{1}{2}$ and NE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Sec. 20: N. $\frac{1}{2}$ of NE. $\frac{1}{4}$, NW. $\frac{1}{4}$.
Sec. 30: W. $\frac{1}{2}$.
Sec. 31: W. $\frac{1}{2}$ of NE. $\frac{1}{4}$, W. $\frac{1}{2}$, SE. $\frac{1}{4}$.
Sec. 32: SW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
T. 32 S., R. 21 E.:
Secs. 1 and 2: All.
Sec. 3: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 10: E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of NE. $\frac{1}{4}$.
Secs. 11 and 12: All.
T. 32 S., R. 22 E.:
Secs. 1 to 17 inclusive: All.
Sec. 18: NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Sec. 20: NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Sec. 21: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Secs. 22 to 26 inclusive: All.
Sec. 27: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, N. $\frac{1}{2}$ of SW. $\frac{1}{4}$.
Sec. 28: E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of NE. $\frac{1}{4}$.
Sec. 34: NE. $\frac{1}{4}$ of NE. $\frac{1}{4}$.
Sec. 35: N. $\frac{1}{2}$, E. $\frac{1}{2}$ and NW. $\frac{1}{4}$ of SE. $\frac{1}{4}$.
Sec. 36: All.
T. 32 S., R. 23 E.: All.
T. 32 S., R. 24 E.: All.
T. 32 S., R. 25 E.:
Sec. 5: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of NW. $\frac{1}{4}$, SW. $\frac{1}{4}$.
Secs. 6 and 7: All.
Sec. 8: W. $\frac{1}{2}$.
Sec. 17: W. $\frac{1}{2}$.
Secs. 18 and 19: All.
Sec. 20: NE. $\frac{1}{4}$ and W. $\frac{1}{2}$ of NW. $\frac{1}{4}$, NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 30: NW. $\frac{1}{4}$ of NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Sec. 31: SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$, W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.

[San Bernardino base and meridian.]

T. 12 N., R. 25 W.:
Sec. 32: E. $\frac{1}{2}$, NW. $\frac{1}{4}$, NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
Secs. 33 to 36, inclusive: All.
T. 12 N., R. 24 W.: All.
T. 12 N., R. 23 W.:
Sec. 28: W. $\frac{1}{2}$, W. $\frac{1}{2}$ of E. $\frac{1}{2}$.
Secs. 29 to 32, inclusive: All.
Sec. 33: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
Sec. 34: W. $\frac{1}{2}$ and SE. $\frac{1}{4}$ of SW. $\frac{1}{4}$.
T. 12 N., R. 22 W.:
Sec. 31: S. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 32: S. $\frac{1}{2}$ of NE. $\frac{1}{4}$, S. $\frac{1}{2}$.
Sec. 33: NE. $\frac{1}{4}$, S. $\frac{1}{2}$ of NW. $\frac{1}{4}$, S. $\frac{1}{2}$.
Sec. 34: All.
T. 11 N., R. 25 W.:
Secs. 1, 2, and 3: All.
Sec. 4: N. $\frac{1}{2}$, N. $\frac{1}{2}$ of SE. $\frac{1}{4}$.
Sec. 5: NE. $\frac{1}{4}$ of NE. $\frac{1}{4}$.

T. 11 N., R. 25 W.—Continued.
Sec. 10: NE. ¼, NE. ¼ of NW. ¼.
Sec. 11: E. ½, NW. ¼, E. ½ and NW. ¼ of SW. ¼.
Sec. 12: All.
Sec. 13: NE. ¼, E. ½ and NW. ¼ of NW. ¼, E. ½ and NW. ¼ of SE. ¼.
Sec. 14: NE. ¼ of NE. ¼.
Sec. 24: SE. ¼ of SE. ¼.
Sec. 25: E. ½ of E. ½.
T. 11 N., R. 24 W.:
Secs. 1 to 18, inclusive: All.
Sec. 19: E. ½, E. ½ of NW. ¼, SW. ¼.
Secs. 20 to 30, inclusive: All.
Sec. 31: E. ½, NW. ¼, E. ½ of SW. ¼.
Secs. 32 to 36, inclusive: All.
T. 11 N., R. 23 W.:
Sec. 1: SE. ¼ of NE. ¼, S. ½ of SW. ¼, SE. ¼.
Sec. 2: SE. ¼ of SE. ¼.
Sec. 3: W. ½ of NE. ¼, W. ½, NW. ¼ of SE. ¼.
Secs. 4 to 9, inclusive: All.
Sec. 10: SW. ¼ of NE. ¼, NW. ¼ of NW. ¼, SW. ¼ and E. ½ of SW. ¼, SE. ¼.
Sec. 11: E. ½, E. ½ and SW. ¼ of NW. ¼, SW. ¼.
Secs. 12 to 36, inclusive: All.
T. 11 N., R. 22 W.:
Secs. 3, 4, and 5: All.
Sec. 6: E. ½, E. ½ and SW. ¼ of NW. ¼, SW. ¼.
Secs. 7 to 10, 15 to 22, 27 to 34, inclusive: All.

The following townships and parts of townships remain withdrawn pending completion of the geologic examination and classification thereof:

Lands withdrawn September 14, 1908, which remain withdrawn pending examination and classification.

[Mount Diablo base and meridian.]

T. 29 S., R. 17 E.: All.
T. 29 S., R. 18 E.: All.
T. 29 S., R. 19 E.:
Secs. 19 to 22, inclusive: All.
Sec. 23: W. ½ of W. ½.
Sec. 26: W. ½ of NW. ¼, SW. ¼.
Secs. 27 to 34, inclusive: All.
Sec. 35: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
Sec. 36: SW. ¼, SW. ¼ of SE. ¼.
T. 30 S., R. 17 E.: All.
T. 30 S., R. 18 E.: All.
T. 30 E., R. 19 E.: All.
T. 30 S., R. 20 E.:
Sec. 6: SW. ¼ of NW. ¼, SW. ¼, SW. ¼ of SE. ¼.
Sec. 7: All.
Sec. 8: W. ½ and SE. ¼ of SW. ¼.
Sec. 17: SW. ¼ of NE. ¼, W. ½, W. ½ of SE. ¼.
Secs. 18, 19, and 20: All.
Sec. 21: SW. ¼ of SW. ¼.

T. 30 S., R. 20 E.—Continued.
 Sec. 27: SW. ¼ of SW. ¼.
 Sec. 28: SW. ¼ of NE. ¼, W. ½, SE. ¼.
 Secs. 29 to 33, inclusive: All.
 Sec. 34: S. ½ of NE. ¼, W. ½, SE. ¼.
 Sec. 35: W. ½ and SE. ¼ of SW. ¼.
T. 31 S., R. 17 E.: All.
T. 31 S., R. 18 E.: All.
T. 31 S., R. 19 E.: All.
T. 31 S., R. 20 E.:
 Sec. 2: SW. ¼ of NE. ¼, W. ½, W. ½ and SE. ¼ of SE. ¼.
 Secs. 3 to 11, inclusive: All.
 Sec. 13: W. ½ of NW. ¼, SW. ¼, SW. ¼ of SE. ¼.
 Secs. 14 to 23, inclusive: All.
 Sec. 24: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
 Secs. 25 to 36, inclusive: All.
T. 31 S., R. 21 E.:
 Sec. 19: W. ½ and SE. ¼ of SW. ¼.
 Sec. 29: W. ½ and SE. ¼ of SW. ¼.
 Sec. 30: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
 Sec. 31: All.
 Sec. 32: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
 Sec 33: W. ½ and SE. ¼ of SW. ¼.
T. 32 S., R. 17 E.: All.
T. 32 S., R. 18 E.: All.
T. 32 S., R. 19 E.: All.
T. 32 S., R. 20 E.: All.
T. 32 S., R. 21 E.:
 Sec. 3: W. ½ and SE. ¼ of SW. ¼.
 Secs. 4 to 9, inclusive: All.
 Sec. 10: SW. ¼ of NE. ¼, W. ½, SE. ¼.
 Secs. 13 to 36, inclusive: All.
T. 32 S., R. 22 E.:
 Sec. 18: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ and SE. ¼ of SE ¼.
 Sec. 19: All.
 Sec. 20: W. ½ and SE. ¼ of NW. ¼, SW. ¼, W. ½ and SE. ¼ of SE. ¼.
 Sec. 21: SW. ¼ of SW. ¼.
 Sec. 27: S. ½ of SW. ¼.
 Sec. 28: SW. ¼ of NE. ¼, W. ½, SE. ¼.
 Secs. 29 to 33, inclusive: All.
 Sec. 34: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
 Sec. 35: SW. ¼, SW. ¼ of SE. ¼.

[San Bernardino base and meridian.]

T. 12 N., R. 27 W.: All.
T. 12 N., R. 26 W.: All.
T. 12 N., R. 25 W.:
 Sec. 31: All.
 Sec. 32: W. ½ and SE. ¼ of SW. ¼.
T. 12 N., R. 22 W.:
 Secs. 25, 26, 35, and 36: All.
T. 11 N., R. 27 W.: All.
T. 11 N., R. 26 W.: All.

T. 11 N., R. 25 W.:
- Sec. 4: SW. ¼, S. ½ of SE. ¼.
- Sec. 5: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
- Secs. 6 to 9, inclusive: All.
- Sec. 10: W. ½ and SE. ¼ of NW. ¼, S. ½.
- Sec. 11: SW. ¼ of SW ¼.
- Sec. 13: SW. ¼ of NW. ¼, SW. ¼, SW. ¼ of SE. ¼.
- Sec. 14: W. ½ and SE. ¼ of NE. ¼, W. ½, SE. ¼.
- Secs. 15 to 23, inclusive: All.
- Sec. 24: NE. ¼, W. ½, NE. ¼ and W. ½ of SE. ¼.
- Sec. 25: W. ½, W. ½ of E. ½.
- Secs. 26 to 36, inclusive: All.

T. 11 N., R. 24 W.:
- Sec. 19: W. ½ of NW. ¼.
- Sec. 31: W. ½ of SW. ¼.

T. 11 N., R. 22 W.:
- Secs. 1, 2, 11, 12, 13, 14, 23, 24, 25, 26, 35, and 36: All.

GEOLOGY.

GENERAL STATEMENT.

The main and subsidiary ranges of the McKittrick-Sunset region consist almost wholly of sedimentary rocks which have been uplifted, folded, and faulted by the intense forces producing the mountains and depressions of this portion of California. Through the subsequent dissection of these upturned and folded sediments, by stream and climatic agencies, the succession of beds can be studied. Thus there have been differentiated the following formations, stated in the order of their age, from earliest to latest. After each formation name appears the name of the time division to which it belongs:

- Franciscan formation (Jurassic?).
- Knoxville-Chico rocks (Cretaceous).
- Tejon formation (Eocene).
- Oligocene (?).
- Vaqueros sandstone (lower Miocene).
- Monterey shale (lower middle Miocene).
- Santa Margarita (?) formation (upper middle Miocene).
- McKittrick formation (upper Miocene to Pleistocene). Represents the Jacalitos, Etchegoin, and Tulare formations of the Coalinga district.
- Fan deposits and stream terraces (Pleistocene to Recent).

With the exception of certain intrusive and metamorphic rocks in the Franciscan, and of two areas of basalt associated with the Miocene beds, these formations consist wholly of marine and fresh-water sediments. The distribution of these indicates that during the region's earlier geologic history sedimentation took place in the sea or its estuaries, but that with the inception of the Pliocene epoch, brackish and fresh water conditions prevailed.

While the problems arising from the study of the region are many and intricate, only those conditions which control the accumulation

and availability of the petroleum products can be fully discussed in a preliminary report of this nature.

It has been found that the Franciscan, Knoxville, and Chico formations are not oil bearing, and that the Tejon formation (Eocene), while possibly affording reservoirs for oil, is not an important source thereof, as it has been shown to be in the Coalinga region. The Monterey and Santa Margarita (?) formations, however, have proved to be the most important sources of petroleum; from these the product has passed downward into the more porous sands and gravels of the underlying Vaqueros (lower Miocene) and upward into the interbedded lenses in the Santa Margarita (?) and also into the deposits of the McKittrick formation, unconformably overlying the Santa Margarita (?) and Monterey formations, where it has largely been retained until tapped by wells. At certain points, however, through denudation or structural disturbance, petroleum products, usually asphaltic, have become associated with the upper part of the McKittrick formation, and even in small quantities with the more recent deposits.

Facts relative to the structural conditions and the physical character of the formations are most important in a discussion of any California oil field, and in none more than in those under consideration, since this region is one of geologic instability.

The following chapters aim to give, as briefly as possible, a statement of these conditions in the McKittrick-Sunset region.

STRATIGRAPHY.

NON OIL-BEARING SERIES.

FRANCISCAN FORMATION (JURASSIC?).

GENERAL DESCRIPTION.

In various portions of the Coast Ranges there exists a complex of igneous and pre-Cretaceous sedimentary rocks, for the larger part intricately flexed, fractured, and faulted, which has been called "the Franciscan formation." Secondary silicification and metamorphism have converted some of the original sandstones into quartzites, shales into slaty rocks and jaspers, limestones into marbles, and have often produced glaucophane, mica, and actinolite schists. Serpentine occurs associated with the Franciscan rocks both in irregular masses and as dikelike bodies.

While certain less-altered facies of the Franciscan sedimentaries resemble the shales and sandstones of the Knoxville, the ensemble of the Franciscan is distinctly unlike that of any later series of rocks in the region. Topographically, the Franciscan has a craggy but in general broadly rounded relief, which strongly contrasts with the parallel strike ridges developed in the post-Franciscan sediments. Drainage lines are developed regularly and show but slightly that

influence of varying rock hardness which so often affects the courses of channels draining areas of later sedimentaries.

The formation contains no diagnostic fossils, so far as known, but upon such evidence as it has been possible to obtain in this region or elsewhere, it is placed within the Jurassic.

ANTELOPE VALLEY AREAS.

The Franciscan formation upon either side of Antelope Valley consists of several elongated areas and a number of small irregular bodies of rocks typical of this formation. Perhaps the most striking of these extends along the southern base of Orchard Peak, where its vivid green and purplish color, due to the presence of serpentine, is in strong contrast with the dull gray and brown of the surrounding Cretaceous shales. At its eastern end near Aido Spring this narrow body consists largely of schists and reddish jasper associated with dark-green metamorphic sandstone. In the direction of Polonio Pass, toward the west, this Franciscan area widens somewhat and serpentine predominates.

A second important body of Franciscan rocks extends along the southwest side of Antelope Valley from sec. 31, T. 25 S., R. 17 E., to sec. 16, T. 26 S., R. 17 E., where it is lost beneath the gravels of Barril Valley. This mass, which is mostly serpentine, with a minor amount of sandstone, is a narrow wedge which has been faulted up diagonally across the strike of the later sediments. A similar wedge of serpentine has been forced up between the Miocene sandstone and Cretaceous shales north and east of McGovern's ranch, and at its northern extremity in sec. 21 occurs a remarkable organic limestone containing fragments of chert and greenstones, but apparently interbedded with the latter.

Another small sheared mass of serpentine lies within the San Andreas fault zone near Carter's ranch. Smaller Franciscan masses lie in secs. 27, 28, 34, and 35 of T. 26 S., R. 17 E., and at that in the canyon of Franciscan Creek (sec. 35) the following succession of rocks has been observed, going downstream:

(*a*) A zone of dark-blue clay, resembling vein gouge; this undoubtedly is due to faulting along the contact with a later series which lies to the south.
(*b*) Blue-green shale—a transition phase of the more siliceous chert and jasper.
(*c*) Green chert—typical chert of the Franciscan.
(*d*) Green sandstone, much sheared.
(*e*) Red and green chert interbedded.
(*f*) Red and green spotted sandstone; this is apparently made up of bits of the adjoining bed and also contains serpentine or greenstone grains, but does not resemble the usual type of sandstone of the Franciscan formation. Its composition indicates a later age than that of the adjacent chert, or than some of the serpentine, at least.
(*g*) Green sandstone—a portion of the above.

All these rocks are much sheared. The organic limestone and the red and green spotted sandstones described above are unusual occurrences, and may mark a later phase of the Franciscan sedimentation than has been heretofore observed.

OTHER AREAS.

In the SE. ¼ sec. 30, T. 27 S., R. 18 E., is an interesting area of Franciscan. While mostly serpentinous, there is at the southern end a patch of light-blue breccia which appears to be a much crushed glaucophane schist; at the northern end of the exposure is a resistant mass of dark-green, fine-grained diorite (diabase?), unlike any rock found elsewhere in this region.

The most southerly area of Franciscan rocks that has yet been noted in the Temblor Range lies mostly in sec. 3, T. 28 S., R. 18 E., where crushed reddish jaspers and serpentine have been faulted into Cretaceous shales and sandstones.

The unusual structural relations between these several Franciscan areas and the neighboring rocks will be discussed under the heading "Structure" (p. 92).

These several surficially disconnected bodies of Franciscan rocks are undoubtedly portions of the old core of the range. This core has suffered so much deformation and at places has been so deeply buried beneath the later sediments that its original continuous character is not obvious; yet, from conditions in other portions of the Coast Ranges, it is safe to assume that the Franciscan forms the basement upon which a large part of the Cretaceous and later sediments have been deposited.

IMPORTANCE WITH RELATION TO PETROLEUM.

So far as known the Franciscan rocks of the Coast Ranges yield no indications of petroleum, and they are important only as a part of the basement complex upon which the younger oil-bearing formations are laid down. The presence of Franciscan rocks at any particular point should alone be sufficient evidence to condemn it for purposes of oil exploitation.

KNOXVILLE-CHICO ROCKS (CRETACEOUS).

GENERAL DESCRIPTION.

The Knoxville-Chico rocks, the next younger in age than the Franciscan, are those deposited unconformably upon it in the ocean during Cretaceous time. These consist of a great thickness of firm, dark-colored shales and sandstones with some conglomerates. They are exposed in four groups of one or more areas each in the McKittrick-Sunset region, and include sediments of both Knoxville and Chico age. A separation of these two formations is not essential to an

understanding of the oil conditions in the region, and has not been attempted, although lithologically the two formations are roughly separable. The Knoxville consists in general of 4,000 to 6,000 feet of black to greenish-brown shales, with minor amounts of dark-green nonnodular sandstone. Some conglomerate occurs within the Knoxville, but it is discontinuous and can not be said to mark a widespread time break. The upper 3,000 to 5,000 feet of the Cretaceous consists of the Chico formation (sandstones with a minor amount of shale). These sandstones are yellowish, massive, and usually contain layers of hard rounded dark-brown nodules, which, more than anything else, serve to differentiate the Chico from other sandstones.

A consideration of the general character of the Cretaceous in the McKittrick-Sunset region leads to the conclusion that the sediments were all deposited under nearly uniform conditions, although toward the close of the Cretaceous either the seas became shallower or the land masses from which the coarser sandstones of the Chico were derived suffered an uplift. Local shallow water conditions are also indicated by the conglomerate zones. Deformational influences appear to have been active before the initiation of the Eocene, and at some point erosion progressed far enough during the uplift following the laying down of the Chico for the complete removal of several thousand feet of sandstone and shale belonging to this formation, before the Eocene or later sediments were deposited, or else the Knoxville overlain by the Eocene was above water in Chico time.

Lithologically, the most characteristic feature of the earlier Cretaceous sediments is their olive-green to greenish-brown color, and of the later sandstones their nodularity.

ORCHARD PEAK AND DEVILS DEN AREA.

The Orchard Peak and Devils Den area lies almost entirely within T. 25 S., R. 17 E., and T. 25 S., R. 18 E., and comprises the high range of mountains forming the southernmost extremity of the Diablo Range as well as some of the lower country in the Barton Hills. Broadly speaking, the shales of the Knoxville formation predominate, and their dark color gives to the region a somber appearance, which is emphasized by its aridity and barrenness of vegetation.

The best section of the Knoxville is that exposed upon the steep scarp which forms the southern face of Orchard Peak, where the beds dip monoclinally northward at angles varying from 30° to 80°.

At the base of this scarp and just above the margin of Antelope Valley are coarse gritty sandstones containing many unrecognizable fossil shell bits. These are overlain by dark greenish shales and spheroidally weathered sandstones, with which are interbedded grayish quartzites and shales at elevations of 1,700, 2,100, and 2,250 feet. Above these are dark grayish nodular shales and moderately

hard sandstone beds. The top of the ridge, at an elevation of about 3,000 feet, is a heavily bedded, dark-green resistant sandstone which gives the summit an unusually precipitous appearance.

In the subsidiary hills known as Sawtooth Ridge, south of the main scarp, the Cretaceous sandstones carry hard dark-brown concretionary layers, which resist weathering and give the ridge a pinnacled topography. Some of these layers are made up of finely comminuted shell fragments similar to those noted at the foot of the main scarp.

The monoclinal structure in the Cretaceous persists with slight modifications from Orchard Peak northeastward to McLure Valley, and the character of the sediments is the same as far as a point near the margin of the valley, where the sandstones are more massive and nodular as well as lighter in color. Chico fossils have been found near Spreckels well, in association with interbedded sandstone and shales.

At the extremity of the high spur which extends southeastward from Orchard Peak, several well-defined conglomerate beds have a nearly vertical attitude. They were traced about three-fourths of a mile and may locally mark the line between the Chico and Knoxville formation.

Two isolated Cretaceous areas lie in the Barton Hills, and both have been definitely determined as of Knoxville age, through the presence of well-preserved *Belemnites* and *Aucella*. The more important of these areas is that extending east and west through secs. 19, 20, and 21 of T. 25 S., R. 18 E., and known locally as Devils Den. The greenish-gray soft shales which are exposed here have been so sheared and crushed that their structure is almost lost. Just at the Devils Den they have been locally hardened by saline waters which exude irregularly from the shale, and differential erosion has produced an intricate system of crags and canyons in miniature. The southern margin of this Knoxville area is in contact with Tejon (Eocene) sandstone and conglomerate, which are overturned against it.

The other area of Cretaceous extends north and south along the crest of the ridge terminating in Point of Rocks, and consists wholly of a similar dark bluish to green soft shale, with some beds of dark-colored sandstone. The series dips to the eastward and owes its presence at the surface to a fault along the west side of the area. Directly over these Knoxville beds lies the Tejon formation. Observed structural conditions alone do not explain the attitude of the Barton Hills Knoxville with reference to the Orchard Peak mass. Not only must there have been faulting immediately following the Chico intense enough to bring the Knoxville up against the sandstones of the Chico, but the Eocene must have been deposited after this relation had been established, and after erosion had removed the overlying Chico, since the Eocene lies directly upon the Knoxville.

AREAS NEAR McGOVERN'S RANCH.

Several small elongated blocks of Cretaceous exist in the vicinity of McGovern's ranch in the central part of T. 26 S., R. 17 E., and these consist in general of typical dark-green, somewhat nodular shales and firm sandstones, considerably faulted and flexed. The exposures along the road 1 mile south of McGovern Gap are characteristic. The investigation of these areas was too cursory to determine whether they are Knoxville or Chico in age.

BITTERWATER CREEK AREAS.

The smaller of the Bitterwater Creek areas lies mostly in sec. 28, T. 26 S., R. 18 E., and probably is a part of the Orchard Peak mass, from which it is separated by the alluvial material filling Antelope Valley. The beds are mostly of dark-colored, evenly bedded sandstone, separated by thinner blackish and rusty shales. The beds have been faulted up against the overlying Santa Margarita (?) formation.

Owing to the denudation of a great anticlinal structure in the shales of the Santa Margarita (?) formation between Barril Valley and Bitterwater Creek, there is exposed an elongated mass of the underlying Cretaceous, which, while conforming in general with the structure of which it is a part, yet shows many minor folds that probably did not affect the incumbent beds at all. This area presents no unusual features; the rocks are dull-green or brown sandy shales and brownish-green plainly-bedded sandstones. The area has not been traced south of Bitterwater Creek.

CEDAR CANYON AND SALT CREEK AREA.

A narrow elongated Cretaceous area occupies the core of the Temblor Range from Bitterwater Creek southeastward to Temblor ranch, and is important, not only because of its size, but because it was the rigid floor upon which the later oil-bearing sediments have been deposited and against which they have been folded. Lithologically the area is uniform, exposures of typical shale and sandstone in Cedar Canyon, at its north end, resembling closely those on Carneros or Salt Creek near Temblor ranch. In this area of Cretaceous rise the best springs of the whole Temblor Range, both in quantity and quality of the water produced. Nowhere in the whole area have fossils been found, but there is no doubt of the Cretaceous age of the series. This is the most southerly exposure of Cretaceous in the Temblor Range, although similar beds occur on both flanks of the Mount Pinos Range at the south end of the San Joaquin Valley.

IMPORTANCE WITH RELATION TO PETROLEUM.

So far as observed in the McKittrick-Sunset region, the Cretaceous rocks are not oil bearing and are important only as forming a platform on which the younger petroliferous formations rest. Much money has been uselessly expended in searching for petroleum in the

Chico, over $70,000 having been thus spent at one point near Devils Den. The presence of Cretaceous rocks at any particular locality, unless they contain a considerable amount of organic shale, should of itself be sufficient evidence to discourage prospecting for petroleum at that point.

TEJON FORMATION (EOCENE).

GENERAL STATEMENT.

The Tejon formation, named from old Fort Tejon in Grapevine Canyon, where it was first described and its fauna first studied, occurs at several places in the McKittrick-Sunset region. It consists usually of rather massive, tawny sandstone, nodular in places, which is easily differentiated from the overlying Vaqueros, but often very closely resembles the sandstones of the Chico. The Tejon is clearly unconformable upon the Knoxville, but its relation to the Chico approaches conformity, a condition which, combined with the close resemblance between the Chico and the Tejon, makes separation difficult.

The extent and continuity of the basin in which the Tejon was deposited is not now discernible; long-continued faulting and the overlap of later sediments have effectually obscured them. Two groups of areas, one comprising most of the ridge between Devils Den and Point of Rocks, and the other two elongated areas between Bitterwater Creek and Temblor ranch, provide the only evidence in this region of what must once have been a widespread deposit.

POINT OF ROCKS AREA.

The largest of the three tracts comprised in the Point of Rocks area consists almost wholly of tawny and light grayish sandstone with a minor amount of sandy shale. The basal beds of the Tejon here consist of a rather coarse greenish to brown gritty sandstone, from which, at several points, characteristic Tejon fossils were obtained.

An unconformity with the underlying Cretaceous is proved by the abundant basal conglomerate of Cretaceous sandstone, quartzite, diabase, and calcareous shale pebbles associated with the fossil reef. The formation is best exposed at Point of Rocks, where the beds dip about 20° NE. The succession there is about as follows, beginning with the uppermost:

Section of Tejon formation at Point of Rocks.

	Feet.
Nodular and cavernous sandstones	550
Massive buff sandstones	350
Nodular sandstones	250
Massive cavernous sandstones	200
Nodular and less conspicuous sandstones	750
Basal grit and sandstones (with fossils)	200
	2,300

The apparent thickening in the Tejon between this place and the northern part of the area is due both to the development of a broad syncline in the northwest part of the area and to faulting which repeats some of the series. It is considered, therefore, that an average thickness of 2,300 feet for the Tejon in this region is not far from the fact.

In contrast with the Eocene of the Coalinga region, the Eocene of Point of Rocks contains only a very minor amount of blackish clay shale, and, so far as observed, none of the light-colored diatomaceous shales which are so important to the oil production in the Coalinga district.

The massive cavernous sandstones referred to in the above table are characteristic of the Tejon. Such are the prominent, isolated croppings at Point of Rocks, long a stronghold of warring desert Indian tribes, which used the natural grottoes and an artificial depression in the sandstone buttes as places of concealment and water storage during siege.

McDONALD'S RANCH AREA.

Through denudation of a northwest-southeast anticline, there have been exposed beds of brownish sandstone, which are tentatively referred to the Tejon, although no supporting paleontologic evidence is available. The best exposure of these sandstones is that along the road just northeast of McDonald's ranch, where they form the regularly arching anticlinal axis of the structure referred to above. Lavender to reddish-brown discolorations in the sandstone at a point northwest of the ranch are among the noticeable characteristics of the supposed Tejon here.

MEDIA AGUA CREEK AND CARNEROS SPRING AREA.

The northwestern end of a belt of sandstones of the Tejon formation is exposed just at the mouth of Cedar Canyon as a massive, somewhat cavernous, yellow sandstone, and retains this character to the region immediately north of the Temblor ranch. A particularly picturesque exposure of the Tejon occurs at Carneros Spring, where the coarse, heavy-bedded, yellowish-brown concretionary sandstone beds, dipping about 30° NE., rise in prominent pinnacles over a hundred feet in height. Surface slopes coincident with bedding planes are also one of the noticeable features at this spring. In general the Tejon is thinner bedded and contains more shale toward the base and is more concretionary toward the top. Owing to the several folds in the Tejon on the flanks of the Temblor Range south and west of Carneros Springs, the apparent thickness of the Tejon is much greater than the actual thickness. A conservative estimate of the thickness of the Tejon in the region west of Carneros Springs is 2,300 feet, the same as that in the region of Devils Den.

IMPORTANCE WITH RELATION TO PETROLEUM.

No petroleum has so far been obtained from the Tejon in the McKittrick-Sunset district, but the pinkish and other discolorations found at certain outcrops are believed by some to be indicative of oil.

OLIGOCENE(?) ROCKS.

DISTRIBUTION AND CHARACTER.

In only two restricted portions of the whole region have rocks of possible Oligocene age been found. The more important of these areas is in the Devils Den region north and southwest of Wagonwheel Mountain. Here a series of massive light-gray and buff nonnodular sandstones, inclosing a fossiliferous reef, are overlain by yellowish and cream-colored calcareous shales. The latter grade upward into gypsiferous gray shales and sandstones that immediately underlie the "reef beds" of the Vaqueros, being separated from the latter by a layer of small, black, slaty pebbles. A section was measured across the series, which dips northeastward, and the following succession of beds from the top downward was found:

Section of Oligocene (?) rocks southwest of Wagonwheel Mountain.

	Feet.
1a. Soft shales and sands with yellowish calcareous layers	200
1b. Gray coarse sandstone with small and large pebbles of quartz and a hard, black metamorphic, apparently a slate, cemented by calcareous material.	75
2. Grayish soft shale, poor outcrops, weathering into a smooth, mouse-colored soil	290
3. Fine-grained gray sandstone, with alternating yellow calcareous layers; outcrops fragmental	115
4. Shale and sandstone bits and fragments; poor outcrops. Some of this sandstone is light gray and firm in texture with quite abundant grains and patches of pyrite	520
5. Gypsiferous sandstone and shale	40
6. Gypsum and sandstone, the former as irregular veinlets	10
7. Grayish to chocolate-colored clay shales with gypsum	125
8. Grayish shaly material with yellow nodular layers	90
9. Pale lavender clayey shale, weathering almost pure white. Not of organic origin	7
10. Grayish and cream-colored shale	18
11. Yellow fine-grained calcareous shale, thin calcite veinlets	10
12. White to cream-colored shale, not well exposed	75
13. Soft gray fine sandy soil (no exposures)	120
14. Yellowish calcareous shale with a hard yellow layer at the top	20
15. Grayish massive light-gray to buff nonnodular sandstone, inclosing fossiliferous calcareous reef	105
	1,820

FOSSILS AND AGE.

The fossils found in the basal beds of this series are as follows:

Lima sp. indet.
Petricola n. sp.
Phacoides n. sp. aff. californica Conrad.
Thyasira n. sp. aff. bisecta Conrad.
Fusus sp. indet.

In a light-brown shale beneath a bluish diatomaceous shale in the NW. ¼ sec. 1, T. 26 S., R. 18 E., the following fossils were collected:

Pecten peckhami Gabb.
Terebratalia n. sp.
Fish scale.
Shark's tooth.

With the exception of *Pecten peckhami* Gabb, which ranges from the Eocene or Oligocene to the Miocene, the stratigraphic position of none of the fossils mentioned is known. The stratigraphic affinities of the beds are with the Eocene, and while the paleontologic are with the lower Miocene, they are possibly to be correlated with the white diatomaceous shale tentatively mapped with the Tejon in the Coalinga district, and may possibly be of Oligocene age.

AREA NEAR BARTON'S.

The smaller isolated area of similar sands and shale lies in the Barton Hills, about 1½ miles north of the former locality and in the same relative position beneath the "reef beds" of the Vaqueros sandstone. The strike of the beds here and their lithology show that they are very evidently a part of the Oligocene(?) rocks.

RELATION TO OIL.

Some of the shales in the area near Wagonwheel Mountain are partly organic in origin and may have been the source of the oil which has been found in the basal Miocene beds of the Barton Hills. No deposits of petroleum or surficial evidence of its occurrence in the formation are known anywhere.

OIL-BEARING SERIES.

GEOLOGIC HISTORY.

Most of the petroleum in the McKittrick-Sunset region is believed to have originated in the post-Eocene sediments; also, since the members of this series in general resemble one another physically and are quite unlike either the Tejon or the Knoxville and Chico beds, it is natural to consider them first as a unit.

Under just what conditions the oil-bearing series were deposited it is now difficult to say. The successive uplifts and depressions of the old land masses and the long-continued, complicated faulting

and folding to which all the sedimentary series have been subjected have greatly obscured the original relations of the post-Eocene sediments. It is unsafe, therefore, to make generalizations as to their thickness, occurrence, and interrelations and apply them alike to the several areas in the region.

It is evident, however, that Eocene deposition was terminated by an uplift which placed much of the Coast Range region, including the Temblor Range, above sea level during the Oligocene, although at the same time sedimentation was probably in progress to the eastward throughout the San Joaquin Valley depression. Miocene sedimentation in the McKittrick-Sunset region was introduced by a uniform lowering of the Temblor Range and the region to the west to a depth sufficient to permit deposition over practically the entire surface. It is probable that the south end of the Diablo Range and most of the Mount Pinos Range were above sea level during this time. Sandstone from a few feet to many hundreds of feet in thickness was first laid down in the region of subsidence, and then followed a period during which diatoms flourished in the waters, and the great deposits of diatomaceous shale of the Monterey and Santa Margarita(?) formations were laid down. During the Santa Margarita(?) epoch, and to a less extent during the Monterey, the quiescent periods of diatom deposition were interrupted by locally turbulent conditions in which coarse granitic conglomerates were carried into the sea and deposited as lenses, which now are intercalated with the diatomaceous shale.

Following the Santa Margarita(?) epoch came a period of uplift and erosion, then another subsidence during which the McKittrick formation was laid down unconformably upon the eroded surface of the older formations. Probably alternating fresh, brackish, and marine conditions followed the marine conditions existing during the earlier part (Jacalitos) of the McKittrick, and it is probable, also, that some of the sediments in the later part (Tulare) may be of continental origin. A period of uplift and deformation of strata, probably in the early Quaternary, began the present geologic cycle.

VAQUEROS SANDSTONE (LOWER MIOCENE).

GENERAL STATEMENT.

The Vaqueros sandstone has a wide extent throughout the McKittrick-Sunset oil region, and is of such importance in connection with the problem of oil accumulation and storage that it will be dealt with in considerable detail. The unconformity between the sandstone of the Tejon (Eocene) and the lower Miocene marks an important hiatus in the succession of beds. Although at many places throughout the region this unconformity is not noticeable, it nevertheless represents

a great time interval, during which much of the Coast Range region was above sea level. In the Devils Den district at least a part of this interval was occupied by the deposition of the Oligocene(?) rocks.

Unlike the simple relations between the Vaqueros sandstone and the beds underlying and overlying it throughout much of the Coalinga district, the relation of the Vaqueros in the McKittrick-Sunset region to the adjacent strata is complex. The various formations have been so involved by complicated structural agencies that they do not dip uniformly toward the San Joaquin Valley, nor lie in a single well-defined belt of sediments skirting the flanks of the Temblor Range. Despite this, the Vaqueros in its more intimate characteristics, as of paleontology, lithology, color, thickness, etc., is quite uniform. It consists nearly everywhere of beds of tawny to brownish, medium-grained sandstones, generally containing many fossils, and nearly everywhere calcareous. The beds are almost always resistant, and hence produce a characteristic reef topography which alone is usually sufficient to distinguish the beds from any others in the region.

In some parts of the region the beds making up the Vaqueros contain two calcareous beds known as "reef beds," separated often by softer somewhat shaly sandstone. Where this double character of the Vaqueros is apparent, as near Carneros Spring, the terms "upper reef" and "lower reef" have been used. The Vaqueros beds are for the most part uniformly arenaceous, but near Annette and upon the southwest side of the Carrizo Plain the sands evidently in part grade into light-colored shales closely resembling the Monterey. The minimum thickness of the Vaqueros sandstone in the McKittrick-Sunset region is probably 60 feet and the maximum about 2,400 feet.

The Vaqueros occurs in numerous related areas, none of them of great size, throughout the McKittrick-Sunset region. On account of their small size they will be described in four districts of several areas each, and one separate area, as follows:

Devils Den district, including about ten areas; the district between Antelope Valley and Bitterwater Creek, including eight or more areas; the district extending southeastward from Bitterwater Creek to a line drawn approximately along Salt Creek and from near its head arbitrarily westward through Wolfort's ranch to the edge of Carrizo Plain, this third district containing three elongated discontinuous areas; and a fourth district, including all the areas of the Vaqueros from Salt Creek southeastward to the southern limit of the region mapped, except the area of Vaqueros lying upon the southwest side of Carrizo Plain, which will be separately treated. This classification of Vaqueros areas is largely artificial, but is necessary in the consideration of such an extensive region.

DEVILS DEN DISTRICT.

Area south of Barton's.—The Vaqueros south of Barton's consists of between 60 and 150 feet of calcareous light-colored sandstone, sometimes pebbly and containing many fossils throughout its length. In places there are two well-defined fossil beds, each about 20 feet thick and 40 or more feet apart. These show slight local variations in thickness, but otherwise are unusually uniform. Characteristic Vaqueros fossils have been collected in this vicinity, most of them from the débris upon the south side of the ridge in sec. 23, known locally as Mastodon Hill.

At the extreme southeast end of this area the Vaqueros sandstone passes beneath alluvial material of much later age, and just at the junction of the two formations there is a tar spring, which flows with about one-fourth inch of strong sulphur water and turns silver coins black almost instantly upon immersion. Small blebs of black oil accompany the water and a thin iridescent film of oil covers the surface. Gas bubbles almost continuously from the mud in the bottom of the spring, which is 4 or 5 feet in diameter. The spring apparently rises in the reef bed and has deposited asphaltum in the reef at several places adjacent to the present orifice. Although the water tastes strongly acid and has an unpleasant odor, it does not seem to be deadly, since large numbers of birds and animals make use of it.

Wagonwheel Mountain area.—The indurated fossiliferous sandstones and the underlying softer beds of this area dip about 30° NE. and extend along the northeast flank of the group of hills, of which Wagonwheel Mountain is the most prominent point. The lowest beds, which may be transitional into the Oligocene(?) to the southwest (see section of Oligocene(?) rocks on p. 40), is a dark gypsiferous shale containing yellow calcareous concretions. About 50 feet below the hard reef these lower beds become sandy and represent the beginning of the change in sedimentation which later produced the "reef beds." The "reef bed" itself is about 60 feet thick and is abundantly supplied with fossils, which weather from the matrix and accumulate in great numbers in the débris about the foot of the steeper faces of the reef. The "reef bed" dips northeastward directly beneath the unconsolidated gravels of the valley, with no croppings of the overlying white shales which are so well exposed in the Devils Den area.

Area south of Dagany Gap.—A slender, elongated S-shaped area of dark-colored fossiliferous sandstone is exposed here through the denudation of an anticline plunging southeast. The bed is between 15 and 25 feet thick and is much less conspicuous than the Vaqueros usually is. It undoubtedly represents a northward continuation of the more prominent beds in the vicinity of Barton's.

Other areas.—Just north of Devils Den itself is a rather thin bed of yellowish fossiliferous sandstone standing nearly vertical and very

evidently faulted into the shales of the Knoxville and the Eocene sandstones that surround it. This area is unimportant except in showing the intense structural modification to which the lower Miocene has in places been subjected. Considerable variation in thickness, apparently due to faulting, has been noted in this particular area. Characteristic Vaqueros fossils were found not far from the little cabin in the NW. ¼ sec. 21, T. 25 S., R. 18 E.

South of Devils Den are several isolated areas of sandstone and sandy shales of the Vaqueros which lie nearly flat upon the Eocene. They are fossiliferous, but unimportant from an economic standpoint, since they are only remnants of what must once have been an extensive area lying unconformably upon the Tejon.

It is evident from the relations of these several areas comprised within the Devils Den district that the Vaqueros formation overlaps unconformably not only both the Eocene and the Cretaceous, but the Oligocene (?).

DISTRICT BETWEEN ANTELOPE VALLEY AND BITTERWATER CREEK.

General statement.—The Vaqueros area southwest of Antelope Valley is intensely disturbed. Close and overturned folding, probably accompanied by faulting parallel to the axial lines and followed by cross faulting in which structures already developed were horizontally displaced, have rendered the problem of formational classification difficult in this region. Indeed, in secs. 25, 26, 35, and 36 of T. 26 S., R. 17 E., the structural conditions are so obscure that separation of the formations has not been attempted. Aside from this vicinity, the Vaqueros is a fairly well defined light-grayish massive sandstone and occupies two elongated areas, one extending from west of Polonio Pass southeastward past McGovern's ranch to the ridge south of Franciscan Creek and the other from the south slope of the same ridge southeastward through Packwood ranch nearly to Bitterwater Creek.

McGovern's ranch area.—The northern end of the area near McGovern's ranch is a broad syncline of massive sandstones and sandy shales, which has been truncated by a narrow block of serpentine faulted up against its eastern end. A section was carefully measured across the south arm of this syncline, and the following succession noted:

Section of Vaqueros sandstone near McGovern's ranch.

	Feet.
Light-colored sandstone and shale	650
Sandy shale, darker than inclosing sandstone	405
Massive cavernous buff, uniform sandstone	650
Dark-colored well-defined bed of shale	80
Massive brownish yellow sandstone	570
	2,355

The following fossils fixing the Vaqueros (lower Miocene) age of the formation have been found in the lower standstones here:

Panopea aff. estrellana Conrad.
Pecten estrellanus Conrad.
Turritella ocoyana Conrad.

Although displacements are common at the base and within the series elsewhere, along the line of the above section no faulting is apparent. Hence the determined thickness of 2,355 feet is not far from correct.

South of the Annette-McGovern Gap road the Vaqueros has been thrown into an anticline, against and through which have been forced blocks and small irregular masses of older rocks. It is, therefore, difficult to state either the succession or the thickness of the Vaqueros beds. In general, they consist of rather soft grayish to buff, sometimes cavernous sandstones, ranging in grain from fine to coarse and conglomeratic, as in sec. 27, T. 26 S., R. 17 E., just south of Imfled's ranch houses, where dark chert and quartzitic pebbles occur. The following Vaqueros fossils have been found in the last-mentioned vicinity:

Pecten bowersi Arnold.
Pecten estrellanus Conrad.
Phacoides sanctæcrucis Arnold.

On the southwest side of this portion of the area the relation to the Cretaceous sandstones is apparently an unconformity where no faults exist. Where the gravels and clays of the upper part (Tulare) of the McKittrick formation overlap upon the southern part of the area there is a striking unconformity in the attitude of the two formations. Along the northeastern flank of the Vaqueros there are evidently beds transitional between the Vaqueros sandstone and the Monterey shale.

Packwood ranch area.—This area, while undoubtedly a southeastern continuation of that just described, is more simple structurally, and for the present purposes may be defined as an anticline which plunges southeast and has been faulted along its axis.

Lithologically, the Vaqueros is here a grayish, massive, nonnodular sandstone in which alternating hard and softer beds have influenced the character of the outcrops and given a somewhat castellated appearance to the steeper slopes. The hills in sec. 17, T. 27 S., R. 18 W., are typical of this topography.

Near the southeastern extremity of the Packwood ranch area the following fossils have been found:

Phacoides acutilineatus Conrad.
Pecten andersoni Arnold.
Leda sp.
Tivela ? sp.

Other areas.—A narrow strip of slightly pebbly, grayish glauconitic sandstone underlies the shales of the Santa Margarita(?) and rests upon the Cretaceous sandstones in secs. 3, 10, 11, and 14 of T. 27 S., R. 18 E. No fossils have been found here, but tentatively this "reef bed" is considered of Vaqueros age, as are the sandstones noted near Shale Point. The latter beds dip about 70° NE. and have apparently been faulted into their present position. They contain the following forms:

Pecten andersoni Arnold.
Pecten crassicardo Conrad.
Balanus sp.

DISTRICT BETWEEN BITTERWATER CREEK AND SALT CREEK.

General statement.—South of Bitterwater Creek the areal character of the Vaqueros is quite distinct from that to the north. Instead of broad, much faulted, and crushed zones, the sandstones are exposed in long, well-defined, narrow areas, usually in sharp contrast with the overlying shales of the Monterey and Santa Margarita (?) formations.

In general, the Vaqueros consists of tawny to chocolate brown, rather calcareous sandstones, containing numerous fossils in most places, and at many points consisting of two separate reef beds, the upper separated from the lower by more or less shaly layers. Where sufficiently well defined, this characteristic of the "reef beds" of the Vaqueros has been indicated upon the geologic map accompanying this report.

McDonald's ranch area.—The same anticlinal uplift upon the axis of which is exposed the area of sandstones of the Tejon, described on page 39, has also exposed the Vaqueros. The sandstone "reef," which is the most marked bed of the McDonald's ranch area, completely incloses the Tejon as an elongated loop nearly 4 miles long. At its southeastern extremity the dark, craggy reef contrasts strongly with the less conspicuous Eocene sandstones beneath and the smooth rounded topography of the later shales. The tunnel and well dug at McDonald's ranch show that the Vaqueros on a fresh surface is quite light in color, of a mealy grain, and rather pebbly. Characteristic Vaqueros fossils were found in this area 1 mile northwest of McDonald's place.

Cedar Canyon–Carneros Spring–Temblor ranch area.—The northwestern end of this important area of Vaqueros is masked somewhat by the overlying gravels of the McKittrick formation, which lies unconformably upon all the preceding beds in this part of the Temblor Range. From the prominent sandstone bluffs at the mouth of Cedar Canyon the Vaqueros is traceable continuously along the northeast slope of the canyon to a point north of Walnut Spring,

thence southeast past Santos ranch and Carneros Spring to the middle of sec. 14, T. 29 S., R. 20 E., a total distance of about 17 miles. Complex east and west folding just south of this last point has disturbed the regularity of outcrops of the Vaqueros. The Vaqueros is particularly well exposed near the mouth of Cedar Canyon, forms a well-marked high bluff of yellow, cavernous, and (toward the base) somewhat nodular sandstone, which extends about parallel with the ridge 3 miles up Cedar Canyon. The beds here dip northeast at angles varying from 30° to 65° and are in strong contrast with the underlying dark-green shales and sandstones of the Knoxville, against which they rest unconformably. This condition is in places accented by the presence of a scattering conglomerate of dark-colored, cherty, and somewhat lighter quartz pebbles.

In the vicinity of Devilwater Creek the reef bed is underlain by sandy shales with some conglomerate, which, while not distinctly resembling the Vaqueros, are probably a part of it, though in some respects the beds resemble the Oligocene (?) of the Wagonwheel Mountain area. A section of these beds measured here is as follows:

Section of the Vaqueros formation and underlying beds at head of Devilwater Creek.

	Feet.
Brown conglomerate	100
Bluish-gray to green shale, hard brown layers, dark-brown fossil reef	50
Blue-gray sandy shale with hard yellow sandstone	
Hard brown layer beneath which is thin-bedded, light-yellow to gray sandstone with hard brown streaks	

In this section, the last two members are doubtfully, while the upper two are certainly, Vaqueros. The lower beds have been represented upon the map by the tint symbol used for "Undifferentiated Miocene."

West of the 2,923-foot point in sec. 7, T. 28, R. 19, a portion of the shales lying above the "reef bed" becomes sandy, extends toward the southeast in a thickening bed (which reaches its best development in the vicinity of Santos ranch), and pinches out in sec. 7, T. 29 S., R. 20 E. This sandstone is called the "upper reef bed" or the "button bed" because of the presence in it of the little button-like echinoderm *Scutella merriami* Anderson. It is separated from the lower bed by sandy shales, which represent a local modification of the usual Monterey shale. In the transition zone between the Vaqueros and Monterey the more sandy facies are mapped as Vaqueros, the predominatingly shale facies as Monterey. In the center of sec. 22, T. 28 S., R. 19 E., an isolated remnant of probable Vaqueros sandstone forms a syncline upon the Eocene sandstones. The Vaqueros also forms a syncline just north of the second ridge north of Carneros Spring.

From Carneros Spring to the southern part of sec. 15, T. 29 S., R. 20 E., the Vaqueros is typical in color and general appearance, and dips monoclinally northeastward beneath the siliceous light-colored shales of the Monterey; but just at the southern extremity the beds begin to show the influence of the cross folding which has produced the remarkably complex conditions just north of Temblor ranch.

The Vaqueros in the SW. ¼ sec. 14, T. 29 S., R. 20 E., consists of 200 feet or more of hard, dark-brown sandstone and conglomerate. This sandstone contains superficially cracked dark-brown sandstone concretions almost exactly similar to those found in the Eocene or Cretaceous beds. Some of these concretions have been elongated into lenses 10 to 12 feet long and 3 to 4 feet through. At the base of these sandstones is a hard layer 6 to 10 feet thick of coarse fossiliferous conglomerate, which is pitted and very resistant to weathering, and is exposed in vertical walls about 20 feet high. Another coarse layer of sand and conglomerate occurs about 60 feet above that just described.

In this preliminary statement it is unnecessary to enter into a full explanation of the peculiar structural conditions north of the Temblor ranch. Two synclines and a faulted anticline developing toward the northeast from a common point in the northwest corner of sec. 26 have produced peculiar fanlike exposures of the Vaqueros sandstone and of the accompanying soft beds which underlie it at intervals and which have been mentioned as possibly of Oligocene age. The Vaqueros here is conspicuous in its croppings, though not of great thickness, and toward the south end is marked by two parallel "reef beds." A section from the spring in the W. ½ sec. 25, T. 29 S., R. 20 E., across the strike of the Vaqueros beds, is as follows:

Section of Vaqueros sandstone in W. ½ sec. 25, T. 29 S., R. 20 E.

	Feet.
Reef bed of hard calcareous, fossiliferous, coarse sandstone layers	80
Coarse, medium-bedded, slightly concretionary sandstone	200
Bluish to brownish shale, crumbly and not well laminated	20
Fine, thinly laminated sandstone, approaching shale in texture	80
Bluish shale, same as above	15
Thin bed of coarse sandstone	5
Bluish to brownish shale, as above	20
Bed carrying *Ostrea* and many other poorly preserved and unrecognizable fossils	25
	445

The Vaqueros is well exposed on the northeast flank of the Temblor anticline on Temblor Creek northeast of the Temblor ranch house, where the following section is exposed.

Section of the Vaqueros near Temblor ranch.

	Feet.
Hard, dark-brown "button bed"	25
Soft sandy beds	175
Reef bed of very hard resistant material	100–200
Soft, medium-bedded, semiconcretionary sandstone	200
Bluish shale and thinly laminated sandy beds, alternating	250
	650

The most southerly exposures of this area lie in sec. 25, just north of the Section Six Oil Company wells. Here they appear as two low, inconspicuous, gray sandstone reefs considerably faulted and not particularly fossiliferous. Their position marks the southeastern nose of a plunging anticline, the faulted axis of which has been assumed as marking the southern limit of this present group of Vaqueros areas. In this region the Vaqueros yields oil of economic value, and in that connection is described later (p. 200).

Area on summit of Temblor Range.—No fossils whatever have been found in the sandstone believed to be Vaqueros on the summit of the Temblor Range, and its age is therefore indeterminate, but from its position beneath certain siliceous and calcareous shales, which are identical in appearance with the Monterey, and because of its lithological resemblance to sandstones of known Vaqueros age, it has been included with this formation. The area is considerably less regular in thickness and distribution than the beds described on the last few pages, but extends more or less continuously from a point about 1½ miles southeast of Sumner's ranch southeastward along the summit of the Temblor Range to a point about one-half mile north of the head of Salt Creek. A discussion of the structural agencies through the action of which this sandstone is exposed will be reserved for a later chapter. Where the Vaqueros first appears upon the ridge between Sumner's and Walnut Spring, the beds of crushed, light-colored sandstones dip 60° NE. toward Cretaceous sandstone and shale which have been faulted up against them upon the northeast. At first glance one would suppose that the siliceous and yellow-banded shales southeast of this sandstone lie beneath it, but a further study of the relations here and to the southeast indicates that the sandstone has been completely overturned and that its position with regard to the shale is not normal. The fault along the northeast border of this sandstone series is traceable almost to the center of sec. 25, T. 28 S., R. 18 E., where it appears to be replaced by an overturned anticline.

In the gulch in the northwest corner of this section the following sequence, showing a gradation between the sandstone and the overturned shale stratigraphically above it, is as follows:

Transitional Vaqueros-Monterey beds in sec. 25, T. 28 S., R. 18 E.

	Ft.	in.
Yellowish, rather firm sandstone		
White sandstone	10	
Yellow calcareous layer, about		8
White sandstone	5	
Thin yellowish calcareous layer		
Whitish sandstone	15	
Pebbly grit	4	
Fine white shale with a thick yellowish calcareous layer		
	34	8

In this vicinity the usual unconformable relation between the sandstone and the Cretaceous shales beneath is evident. From this unconformable exposure southeastward the sandstone, while well exposed, is less continuous and is at some places greatly flexed, while at others, notably in sec. 4, T. 29 S., R. 19 E., it appears to be a simple monocline dipping about 15° NE. and bounded upon its southwestern side by a well-defined, though probably minor, fault.

Topographically this upland country is smooth and rolling, and at best the Vaqueros exposures are not prominent, but toward the southeast, where Santos Creek and other streams drain into the San Joaquin Valley, they encroach upon the Vaqueros, which becomes a more prominent topographic feature. Thus in the syncline crossing the head of Carneros Canyon the sandstones are exposed in buttress-like tawny croppings similar to those near Santos lower ranch.

There is little or no doubt that the sandstone from the San Luis Obispo County line southeastward to Salt Creek is of Vaqueros age, for near the north line of sec. 19, T. 29 S., R. 20 E., several bivalves suggesting the lower Miocene were found upon the northeast flank of the syncline.

VAQUEROS SOUTH OF SALT CREEK.

General statement.—Within the region south of Salt Creek, which is the most important economically of the whole area studied, the largest single mass of the Vaqueros extends along the summit of the range in an elongated, rather indefinite area extending southeastward from the much-faulted region north of White's camp to sec. 15, T. 32 S., R. 22 E., where it is faulted out of sight beneath the overlying shales.

Other areas in this region lie upon the southwest flank of the Temblor Range and in the hills drained by the several branches which unite to form Bitter Creek. Because of the intense faulting upon the Carrizo Plain slope of the Temblor Range it has been difficult to properly differentiate the sedimentaries there, and all statements concerning not only the structure but the age of the sandstones described as Vaqueros must be considered as merely tentative. Until extended detailed work can be done in this region definite statements are to be avoided. Except for the narrow well-defined bed of Vaqueros mak-

ing up the base of the Miocene of the south arm of the Temblor anticline and for the Bitter Creek area, no Vaqueros has been found upon the northeastern flank of the Temblor Range south of Salt Creek.

Area on summit south of Salt Creek.—The northern end of this area is much shattered by blocks of old granitics and schists which have been faulted up, apparently from a very great depth. Especially upon the southwest side of the range the Vaqueros sandstone is sheared. Further, the relations of the Vaqueros to the rocks immediately adjacent are masked by gravels of the McKittrick formation, which here lies unconformably upon all older rocks. Upon the northeastern slope of the mountains the sandstone extends northwest and southeast as a narrow zone steeply tilted to the northeast and is overlain by calcareous and arenaceous shales, apparently of Monterey age.

The base of the sandstone here has been faulted down against a schist block, so that the determination of the original thickness of the sandstone is not possible. The Vaqueros in this vicinity is a light-brown, much-softened sandstone, containing narrow bands of dark-brown to blackish shale which seem to be more prominently developed upon the southwest side of the summit than upon the slope toward Crocker Canyon. The heavily bedded sandstone in the axis of the anticline, about 3 miles north of White's camp, has a concretionary tendency, the concretions being irregular and from 10 to 12 feet in diameter. The material is a fairly coarse granitic sand with a few black grains scattered through it. In the vicinity of Smith's wells the dark shales associated with the Vaqueros carry considerable sulphur. Characteristic exposures of the Vaqueros in this area are obtained along the new graded road between Crocker Spring and White's camp, where the buff to brownish, rather coarse sandstones, with intercalated shales, are shown upon the cuts of the road.

From the Crocker Spring and White's camp road southeast along the slope of the range, the sandstones are bounded upon both the northeast and southwest sides by faults. They have been complexly folded and are so crushed and softened that the usual rather bold exposures characteristic of Vaqueros are not to be found there. In sec. 5, T. 32 S., R. 22 E., the normal relations of the Vaqueros to the overlying shales can be noted upon the southwest slope of the 3,550-foot point. This slope is steep from the summit downward for about 1,500 feet, where the underlying sandstones occupy the east arm of a local anticline and pass beneath the shales which here make up the summit of the range. Unless this condition is due to an overturn of the sandstones a normal relation to the shales is definitely established. This condition continues only about a mile to the southeast, where the shales are again faulted against the sandstone.

At its southern end, the sandstones of this area appear to be monoclinal, with dips of 30° to 70° SE. Through the coalescence of the two faults bounding the Vaqueros, the broad area of sandstone narrows to a wedge, which ends just at the north line of sec. 15.

Areas on southwest flank of Temblor Range.—A number of disconnected areas of sandstone, which are presumably of Vaqueros age, have been noted upon the southwest flank of the Temblor Range. Their structure is usually obscure and they have been mapped with an attempt only at approximate accuracy. They may be described as generally coarse to medium grayish and brownish yellow sandstones, which nearly always have been greatly softened and sheared by the faulting to which they have been subjected. The three areas east of Wolfort's ranch occupy the axis of an anticline which has been faulted upon its southwest arm so that the sandstones now occupy a normal position with reference to the overlying shales only upon their northeast side. About 1½ miles southeast of Sandiego Joe's, a small area of sandstone, presumably of Vaqueros age, is exposed upon the axis of an anticline. Similar exposures occur to the southeast along this same axis and an elongated area of Vaqueros is faulted up against the McKittrick in the southeast part of T. 30 S., R. 20 E. There the beds of this area are apparently overturned, but toward the southeast in sec. 6, T. 31 S., R. 21 E., they form a normal anticline and plunge southeast, passing beneath the Monterey shale.

Crocker Spring area.—One-half mile due west of Crocker Spring there is a zone of supposed Vaqueros sandstone extending northwest and southeast, along the southwest side of which there is a fault. The sandstone in this zone is hard, gray, and moderately coarse-grained, and is immediately overlain by a dark-brown shale with one or two interbedded sandstone layers, each probably a couple of feet in thickness. Above these sandstone layers are regular dark yellowish-brown calcareous layers and concretions. From here upward in the series the material is transitional into hard porcelain shales with occasional yellowish layers.

Vishnu area.—In sec. 23, T. 32 S., R. 22 E., about 1 mile east of the Vishnu well, and extending southeast along the flank of the Temblor Range to sec. 4, T. 11 N., R. 25 W., there is a narrow area of the Vaqueros formation. This area consists of brown shale and a coarse sandstone which has been stained somewhat pink in places by oil. It may be considered within the transitional zone of shale and sandstone between the lowest Monterey and the highest Vaqueros. This sandstone has certainly been faulted along its southwest margin, but may be in normal contact with the shales toward the northeast.

Bitter Creek area.—In the southern half of T. 11 N., R. 24 W., is a roughly elliptical area of Vaqueros which extends from Cienega

Creek on the southeast to the head of Elkhorn Plain on the northwest. These sandstones are overlain upon the northeast by the Monterey shale and are bordered on the southwest by the shales of the Santa Margarita (?) formation, which, except at the head of the gulch in the southwest corner of sec. 28, has completely obscured the Monterey shale. Two major structural lines cross this area from northwest to southeast and have been instrumental in exposing the sandstone at the surface. This sandstone is in general evenly bedded, usually coarse and granitic. In some places, notably in the canyon back of Sunset, it is concretionary and is often well impregnated with oil. It is undoubtedly a part of the same series that is so well exposed upon the southwest flank of the Temblor Range near the Smith and White camps. This area is the most southerly of the supposed Vaqueros that has so far been examined in the Temblor Range.

AREAS ALONG THE SOUTHWEST MARGIN OF CARRIZO PLAIN.

A rapid reconnaissance along the foothills of the southwest side of Carrizo Plain from García's ranch to Painted Rock ranch showed the existence of a series of faulted and folded sandstones and interbedded shales which are, in part at least, of Vaqueros age.

One of the best sections of the Miocene in the whole McKittrick-Sunset region is that exposed on the southwest flank of the syncline in the southeast quarter of T. 29 S., R. 17 E., and in this the Vaqueros is a series of rather soft, tawny and gray, medium to coarse sandstones, which has here a total estimated thickness of 1,000 feet. The transitional character of the uppermost sandstone of the Vaqueros into the Monterey shale overlying it is clearly shown in this section.

The Vaqueros in this vicinity is associated with dikes of diabase, which were intruded into the soft greenish-brown shales below the reef beds before the deposition of the sandstone, since rounded basal pebbles of diabase are found in the Vaqueros. Other dikes and sills of similar rocks, on the other hand, are definitely intrusive in the Vaqueros, and even, as in sec. 5, T. 30 S., R. 18 E., penetrate the Monterey shale. Except within this limited area and at a single point about 8 miles southeast, there are no exposed Miocene intrusives in the McKittrick-Sunset region.

A typical Vaqueros fauna has been collected from the beds about 1½ miles due west of Painted Rock ranch, where light-colored, well-bedded sandstones dip northeast against a faulted block of brownish-yellow hard shales of doubtful age.

Northwest of the Painted Rock ranch similar yellow shales are interbedded with sandstones which may be of late Miocene age. The relations are most clearly evident in the broad anticline occupying the hills about a mile west of bench mark 1930, in secs. 4, 5, 8, and 9 of

T. 31 S., R. 19 E. Here the white medium-bedded nonnodular sandstone at the axis of the fold is overlain by sharply contrasting beds of hard yellow and buff shales, beautifully exposed in the ridge upon the northeast arm of the anticline. The shales are overlain by grayish, medium-grained, well-bedded, northward-dipping sandstones, which outcrop prominently in the spurs and knobs in secs. 30, 31, 32, and 33 of T. 30 S., R. 19 E. The upturned beds are offset and sheared by vertical north and south faults, which traverse the strike of the series at right angles.

An interesting sand-filled and cemented fracture, which belongs to the same system as the faults, extends northward across sec. 4, T. 31 S., R. 19 E., from its southwest corner, and resembles a low, partly demolished wall, especially from the south. Upon the summit of the ridge in the SW. ¼ sec. 32, T. 30 S., R. 19 E., parallel to and just east of the fault which brings sandstone against shale, a basic dike 3 or 4 inches wide penetrates the shale. Although of finer grain, the rock resembles that several miles northwest.

The age of this series of shales and sandstone is not at present known; hence upon the geologic map only the lithologic differences and structural conditions are indicated.

THICKNESS OF THE VAQUEROS SANDSTONE.

The following figures are based upon paced meanders or estimates made in the field and represent either minimum-maximum measurements or averages for a given locality:

Thickness of Vaqueros sandstone in McKittrick-Sunset region.

	Feet.
Devils Den region	25–150
Near McGovern ranch	2,300
Near McDonald ranch	300–450
At Napoleon Spring	530
Media Aqua Creek (including 2 "reef beds" and included shales)	800
Three-fourths mile south of McAllister's ranch on road	300
Near spring in sec. 25, T. 29 S., R. 20 E	450
Hills 7 miles west of Simmler	1,000

MONTEREY SHALE (LOWER MIDDLE MIOCENE).

INTRODUCTORY STATEMENT.

The term "Monterey" has been applied by previous writers to the whole of the prominent series of white shale extending uninterruptedly from just east of Polonio Pass southeastward along the flank of the Temblor Range nearly to Temblor ranch, and to the great area of shale embracing practically all of the range from the head of Salt Creek southeast to the limits of the region studied. The examination carried on during the past season has shown that this shale is separable into two formations, one of which is thought to be the equivalent of the

Santa Margarita(?) formation (upper middle Miocene) in the Coalinga region, while the earlier more closely resembles the Monterey (lower middle Miocene), as it has been described in other parts of the State. Definite paleontologic evidence for the separation in the McKittrick-Sunset region has been scant, but beyond the limits of the mapped area, west of Polonio Pass and upon the southwest side of Cholame Valley, white shaly beds that are believed to be equivalent to the diatomaceous beds of the Antelope Valley locality are known to overlie beds of Santa Margarita age. The main consideration involved in the present separation of the rocks, however, is one of convenience to the prospector. Since there is a marked difference in the physical appearance of the rocks, it simplifies an understanding of geologic and structural conditions, both important in governing the distribution of petroleum, if the separation into Monterey shale and Santa Margarita(?) formation be made. The rocks included within the Monterey are considered to be the source of much of the petroleum in California, and so have been studied in considerable detail.

GENERAL DESCRIPTION.

The general characteristics and origin of the Monterey formation have been fully described in Bulletin 322 of the United States Geological Survey, and this description will apply with slight modification to the rocks of the McKittrick-Sunset region.

Broadly speaking, there are but two great Monterey provinces in the McKittrick-Sunset region. One begins just south of Polonio Pass and extends southeast along the northeast face of the Temblor Range nearly to Temblor ranch, where it terminates abruptly in the belt of cross folding affecting the Vaqueros and older rocks. The other and larger area of Monterey begins in the San Andreas fault zone immediately east of Sumner's ranch in sec. 31, T. 27 S., R. 18 E., extends southeast along the southwest side of the Temblor Range to the vicinity of Wolfort's ranch, where it rapidly broadens to include practically the whole mass of the range, and so persists southeastward to the limits of the region studied.

The Monterey of the McKittrick-Sunset region consists of a series of brownish to light-yellow shales, usually well bedded and resistant to weathering, which are largely of organic origin. The lowest portion of the series is usually made up of calcareous and arenaceous shales which represent a transition into the sandstones and fossiliferous beds of the Vaqueros. These grade upward into typical siliceous and argillaceous shales that contain evidence of organic origin. Prominent zones of nodular calcareous shales are characteristic of this middle portion of the series. The upper third of the formation includes an indefinite zone of sandstone beds that are irregularly -calated in limy-siliceous shales. The succession and character of

these sediments coincides very closely with those of the lower division of the Monterey in the Santa Maria district. The upper division, so prominently developed near Lompoc, in the Santa Maria district, is absent from the McKittrick-Sunset region, unless the basal organic shales of the formation here described as Santa Margarita (?) formation are the same as those described as upper Monterey in the Santa Maria report.

The conditions under which deposition of the Monterey shale of California took place were unique and are not yet entirely understood. Most of the Cretaceous and practically all of the Tertiary deposits up to those of middle Miocene time, with the exception of certain Eocene or possibly Oligocene shales in the Coalinga region, are of mechanical origin. But with the sharp change in conditions at the close of the Vaqueros epoch, a new type of sedimentation began. With a few alternating returns to shallow-water conditions, indicated by the transitional sandstone beds at the base of the series, the ocean floor was evidently greatly depressed, and the area of land surface correspondingly restricted.

The waters of this ocean were scantily supplied with molluscan life, but must have teemed with the minute foraminifera and diatoms, the skeletons of which, falling to the ocean bottom, have formed such a great bulk of the Monterey shale. After the major portion of the lower division of the Monterey had been deposited, there must have been a partial return to the shallow-water conditions which resulted in the production of local areas of sandstone, some of them fossiliferous. That portion of middle Miocene time which succeeded the period of sandstone deposition was peculiarly adapted to the growth of diatoms, the remains of which make up a high percentage of the shales above the upper sandstone horizon.

The Monterey shale has been subjected to a varying degree of alteration, none of it pronounced enough, except in certain restricted localities, to greatly change the appearance of the formation. Silicification has taken place, however, especially in the lower and middle portion, but the process by which the silica was so intimately introduced into the shales is not fully understood. A suggestion is at hand in secs. 13 and 14, T. 30 S., R. 21 E., where an intense local silicification has taken place along fractures in a much folded and possibly faulted zone of the Monterey. The rock has been so altered as to closely resemble both in hardness and color the grayish-green phases of jasper and chert seen in the pre-Cretaceous Franciscan formation. It is conceivable that solutions percolating along similar, though perhaps smaller, fractures resulting from the folding and faulting to which the Monterey shale has been subjected have produced a less intense but none the less definite silicification in other parts of the series.

ANTELOPE VALLEY—TEMBLOR AREA.

The northwestern extremity of the Antelope Valley–Temblor area is a narrow zone of arenaceous shales with some thin beds of sandstones, which occupies the axis of a broad syncline in the NW. ¼ T. 26 S., R. 17 E. The transitional character of these beds into the underlying Vaqueros is clear there. This particular portion of the area is truncated by a fault at its southern extremity and so is separated from the rest of the series extending along the southwest side of the valley and thence southeastward. The shales here are strongly deformed and faulted. The original soft, somewhat sandy character, due to their transitional position with reference to the Vaqueros, has aided in obscuring the structure. On the west side of the south end of Barril Valley a prominent point is occupied by a thick fossiliferous sandstone bed intercalated in the shales. It is a light-gray rock which contains calcite in veins and small masses and varies from fine to coarse in texture. This arenaceous phase of the Monterey, with occasional lenticular sandstone beds, extends through the hills in front of Packwood's ranch and becomes more calcareous toward the southeast. The following section across the northeast area of the faulted anticline south of Packwood's shows the general character of this part of the formation. The section is based on a paced meander from southwest to northeast along the ridge extending diagonally across sec. 16, T. 27 S., R. 18 E., and certainly includes in its upper portion diatomaceous beds classed upon the map as Santa Margarita (?) formation.

Section of middle Miocene in sec. 16, T. 27 S., R. 18 E.

		Feet.
Santa Margarita (?) (3,500 ± feet).	Grayish white shales to synclinal axis	650
	Pearl-gray shales	220
	Grayish to white shales with quartzitic sandstone dikes across bedding, also large cream-colored nodules	1,330
	Soft shale and plentiful yellow layers; upper portion contains some hard white shales	360
Monterey (3,500± feet).	Punky gray shales with several yellow calcareous layers	900
	Soft gray shale with calcareous, and near top gypsiferous layers	295
	Rather punky gray shales with layers of yellow calcareous beds	650
	Gray sandstone with fossil pectens	150
	Poorly exposed white shales, probably vertical	860
	Light-gray thin-bedded shales with thick yellow layers	180
	Gray shales with thin yellow layers	290
	Soft yellow and gray shale	280
	Thin-bedded and shaly sandstone	450
	Gray sandstone	130
	Fault zone, crushed shale and sandstone, structureless in beds, transitional to Vaqueros	255
		7,000

The succession and character of the beds exposed in this section are typical of the Monterey from Bitterwater Creek southeastward for a number of miles—briefly, a series of calcareous and clayey shales, arenaceous toward the base and organic in the upper portion.

The smooth, rounded, and tentlike topography which distinguishes both the Monterey and the Santa Margarita (?) is particularly evident in the hills along the northeast side of Cedar Canyon, as seen from above Packwood's. There is a strong contrast between these bright smooth slopes and the somewhat rugged bluffs of the Vaqueros or the somber Cretaceous mass upon the south side of the canyon.

From Santos ranch southeastward the character of the shale changes somewhat. The whole series becomes less clayey and more diatomaceous, especially in the foothill region due east of Carneros Spring. The following succession of beds has been noted in the canyon about 3½ miles east of the spring, beginning with the uppermost Monterey:

	Feet.
Soft white to lavender organic shales	2,800
White well-bedded shales with limy layers	3,000

Most of this section is exposed in steep northeastward dipping beds of shale along the south side of the canyon. In secs. 2, 11, and 12 the shales are well impregnated with petroleum, which has been prospected in times past at a series of pits dug along the most productive portions of the shale. On the steep bluff in the NE. ¼ sec. 11 the succession in these beds is as follows:

Section of middle Miocene in sec. 11, T. 29 S., R. 20 E.

Hard grayish white shale with yellow layers considerably impregnated with petroleum.
Fine hackly shales considerably impregnated along bedding planes.
Massive arenaceous shales with yellowish limy layers.

A total thickness of about 500 feet is included in these beds.

SANDSTONE DIKES IN MONTEREY SHALE.

Upon a hill in the southwest quarter of sec. 3, T. 29 S., R. 20 E., yellow Monterey shale is traversed by three sandstone dikes which strike slightly east of north and dip about 60° W. The lower is about 8 feet thick and the middle and upper about 18 and 8 feet, respectively. They consist of rather uniform, fine to medium grained granitic sand, and are longitudinally seamed with irregular calcite veins varying from a mere thread to an inch in thickness. Although the structure is not discernible in these dikes, they weather to a rough and pitted surface on which the calcite veins stand out and give a false appearance of bedding. Several shale inclusions were noted in the sandstone of the dike.

DISAPPEARANCE OF MONTEREY SOUTH OF GOULD HILLS.

A broad overlap of the gravels and shales of the McKittrick, in conjunction with cross folding, has buried the Monterey south of Gould Hills, except where two V-shaped remnants are left in the axes of two closely-folded synclines north of Temblor ranch. These small areas indicate a former connection between the area just described and that to follow. In fact, it is most likely that the broad Cretaceous and Eocene core of that part of the range which extends from Cedar Canyon to Temblor ranch was once completely covered by Monterey shale.

SUMNER'S RANCH–SUNSET AREA.

The Sumner's ranch–Sunset area of Monterey is the most important in the region under discussion, although at its northwest end it is a mere strip of calcareous yellow shale which is undoubtedly truncated at a very low angle by the fault along its southwestern margin. The exposures in the creek bed just east of Sumner's house are a much folded and silicified calcareous shale in which springs rise and flow into Bitterwater Creek. The exposures of Monterey thence southeast are not of the best, owing to severe crushing, yet it is evident from the abundance of calcareous nodules that the horizon is near the base of the series, a position which is definitely established a short distance farther southeast by its relations to the overturned Vaqueros along the summit of the range.

From near Wolfort's, the area broadens and swings across the Temblor Range so as to include a much greater bulk of the mountains. A large part of the eastern half of this wider portion is a single great synclinal structure which begins in a series of faults north of Wolfort's and extends southeastward along the range for about 18 miles. Santa Maria Valley and the high flats southwest of Temblor ranch are the topographic expression of this structure. At its northwestern end the shales are interbedded with quartzitic gray sandstones well shown along the road between McKittrick and Simmler just east of the summit. These sandstones are believed to be a portion of the zone of lenticular sandstones noted elsewhere in the area, particularly in the vicinity of Crocker Spring and along the eastern slope of the range southwest of Midway and Spellacy Hill.

Although the series maintains its calcareous character, there appears to be an increase in the degree of silicification from Sandiego Joe's southeastward. This is shown by such bands as the continuous zone of almost cherty shale extending from just southwest of the 4,110-foot point in sec. 10, T. 30 S., R. 20 E., along the summit of the range to Crocker Spring. A similar siliceous stratum, in which the shale is of a porcelaneous type, lies near the top of the Monterey. It appears to be a silicified diatomaceous shale.

The steep southwest wall of Salt Creek canyon exposes a fine section of the Monterey, which is there a southwest dipping monocline of platy, limy, siliceous yellow shale, containing hard yellow, limy concretions which are seamed with numerous small calcite veins. After long exposure to the weather, the less resistant portion of the concretions is dissolved away and the harder veinlets left in bas-relief. This sort of weathering is typical throughout the whole series, wherever there is differential hardness in the calcareous portions of the shales. Of such character are the shales a couple of miles west, and as far south, of Frazer Spring.

This phase of the shale occurs also at the south end of Santa Maria Valley in the broad flat-topped ridge lying mostly within sec. 6, T. 31 S., R. 22 E.

The topography of the uppermost beds of the Monterey southwest of Midway contrast rather sharply with the lower smooth slopes of the softer shales of the Santa Margarita(?) formation. The former is clayey and carries more numerous and more thinly bedded brownish-yellow calcareous concretions than exist higher in the series. The steeply northeastward dipping shales at Crocker Spring are probably in this upper zone of the Monterey.

In all the folded upland region along the summit of the Temblor Range there is little lithologic variation in the Monterey shale except that due to folding or faulting. The intergradationary character of the Monterey and Santa Margarita(?) and their close resemblance is, nevertheless, very evident along this zone; beds of coarse granitic cobbles, such as characterize the typical Santa Margarita, are found well down in the transitional beds, and even at one place in a canyon near the center of sec. 11, T. 32 S., R. 22 E., are intercalated with shales of a distinctly Monterey character.

Immediately west of Maricopa, near the brea deposits, beds of coarse granitic sandstone from 1 to 2 feet in thickness are interbedded with platy diatomaceous and gypsiferous shales. These contain fragments of shale and of the yellow limestone concretions which are common in the calcareous shales. Although some of this sandstone may be in the form of dikes, the fact that it parallels the bedding, together with its occurrence as lenses elsewhere in the field, leads to the conclusion that it exists as true beds. The change from sandstone to shale is very sharp. A saline spring, the waters of which carry blebs of oil, rises in the shales here and has been instrumental in producing the bed of brea near by.

In the SW. ¼ sec. 21, about 3 miles southwest of Maricopa, yellowish-brown shales and thin-bedded granitic sandstone and sandy clays are interbedded and form the transitional beds at the base of the Monterey.

The most southerly portion of the Monterey area within the region studied lies south of the Pioneer group of oil wells, and a paced section running from sec. 24 southwest into the NW. ¼ sec. 25, T. 11 N., R. 24 W., gives the following measurements:

Section of Monterey shale south of Pioneer oil wells.

	Feet.
Hard siliceous shales with yellow layers	1,700
Fine white and yellow shales	700
Calcareous and arenaceous shale with calcareous nodular layers	500
	2,900

The fairly constant character of the Monterey shale throughout the whole McKittrick-Sunset region is evident in a comparison between this section and those made in other parts of the area.

A tongue of brownish to gray and sulphur yellow diatomaceous shale of Monterey age is exposed just at the edge of the map in sec. 32 of T. 11 N., R. 24 W. It is overlain directly by the Santa Margarita(?) formation, which here consists largely of shale fragments. The poverty of the Monterey in paleontologic remains is here, as elsewhere in the State, very striking. With the exception of a few *Pecten peckhami* Gabb, *Macoma*, *Arca*, a single specimen of *Dentalium*, some bits of fish scales and bones, and ostracod impressions, the shales have yielded nothing which would assist in determining the age of the series. The establishment of this point has, therefore, been based upon its general lithology and position with relation to formations of known age.

IMPORTANCE WITH RELATION TO PETROLEUM.

The organic matter in the Monterey shale is believed to be the source of at least a part of the oil in the McKittrick-Sunset region; its presence or that of the Santa Margarita(?) is therefore believed to be necessary for the accumulation of petroleum in this territory. Most of the hydrocarbon content has migrated to other formations, and entered the Vaqueros below or the McKittrick above, so that as a reservoir the Monterey is not important. An exception to this statement might be made in case of the interbedded sands near its base or in the transition zone between it and the Vaqueros. The Monterey is important, however, as the cap which overlies the oil in the Vaqueros, and through which one must drill to reach it. For this reason a study of the thickness of the Monterey and of the structural lines which affect it are important in determining where the probabilities are greatest for securing commercial quantities of oil.

SANTA MARGARITA(?) FORMATION (UPPER MIDDLE MIOCENE).

GENERAL STATEMENT.

The reasons which have led to the correlation of the diatomaceous upper portion of the shale series in the McKittrick-Sunset region with the Santa Margarita formation have been given in the discussion of the Monterey shale. (See pp. 55–56.)

The Santa Margarita in portions of the Coast Ranges is separated from the Monterey by a great unconformity, as at points along the west side of the Salinas Valley. Elsewhere an apparent conformity between the two formations is the rule. Although conformity prevails over the greater portion of the region under discussion, both of these conditions are found here.

For convenience of discussion the region has been divided into areas, each of which is described below.

AREA IN DEVILS DEN DISTRICT.

A roughly triangular area of Santa Margarita(?) occupies the hills extending south from Dagany Gap to Emigrant Hill and west almost to Devils Den. It consists of a series of calcareous and diatomaceous shales, very regularly bedded, which lie in direct contact with the Vaqueros. The complete absence of the Monterey here indicates that the conditions attendant upon the deposition of the Santa Margarita(?) were similar to those in the Coalinga region.[a]

The area is, in fact, the southeast termination of the anticline of Pyramid Hills and the great syncline of McLure Valley, although the simplicity of both structures is here disturbed by the development of many minor folds.

The following section of the full thickness of the formation is based upon a paced meander from the reef bed in the NW. ¼ sec. 11, T. 25 S., R. 18 E., northeastward along the gulch heading near the reef, to the region of the Kettleman Plains in sec. 2.

Section of the Santa Margarita (?) formation in secs. 2 and 11, T. 25 S., R. 18 E.

	Feet.
Argillaceous and diatomaceous dove-colored shales showing near top some evidence of impregnation	1,200
Thin-bedded whitish to yellow shales with russet-colored layers at base	600
Reef bed of fossiliferous sandstone about 75 feet thick (Vaquerous).	
	1,800

This succession and thickness of shales is maintained throughout the area. The topography of the shales is characteristic. The terms "Tent Hills" and "Pyramid Hills," applied to occurrences of the Santa Margarita(?) farther north, fitly describe the appearance of the groups and rows of white or yellowish steep-sided though smooth hills in this vicinity.

[a] Bull. U. S. Geol. Survey No. 398, pp. 88–94, 174–176.

AREAS IN BITTERWATER DISTRICT.

Although, strictly speaking, the larger of the two areas in the Bitterwater district might be broken up into several smaller isolated portions, the structural unity of the whole is unbroken. It begins near Polonio Pass as a faulted block of light-colored diatomaceous shale, with some interbedded sandstones. extends southeastward along both sides of Raven Valley, and finally passes beneath the gravels of the San Joaquin Valley in sec. 28, T. 27 S., R. 19 E. On the northeast side of this pass, in secs. 30 and 32, there are three small isolated areas of light-colored organic shales, which dip against and under beds of Cretaceous age. They are undoubtedly the exposed portions of a wedge of Santa Margarita(?) shale which has been thrust under the older Cretaceous beds to the northeast, during some of the intense deformational action to which the region has been subjected. Except for a small exposure in sec. 33 the series does not appear elsewhere at the surface on the north side of Antelope Valley.

At McGovern Gap, however, the following approximate section has been measured:

Section of Santa Margarita (?) formation at McGovern Gap.

	Feet.
(*a*) White and bluish-gray easily fractured shale	150
(*b*) Fine-grained brownish sandstone with some shales	395
(*c*) Calcareous organic shale, well bedded and light in color. Contains some sandy layers	1,200
(*d*) Sandstone beds with some shale intercalated	300+
	2,045

South of this are nodular typical shale and dark-green sandstone of the Cretaceous which have been faulted up against the Miocene.

A slight lavender tint in the sandstone toward the top of the series is the only indication of petroleum in the vicinity. The conditions of deposition were not particularly stable, since within a mile southeast a geologic section shows that (*a*), the uppermost shale, has thickened to 500 feet while (*b*) is represented by only a few layers of sandstone. Similarly the 1,200 feet of organic shales are reduced in thickness to but 700 feet, while the lowest sandstone bed (*d*) becomes shaly and increases to a thickness of some 400 feet. Such facts indicate local variations in quantity and quality of the material deposited, a characteristic of sedimentation found nearly everywhere in the State, even among the oldest rocks.

The northeast limb of the great Raven Valley anticline is a series of soft drab diatomaceous and somewhat harder calcareous shales with some intercalated harder clay shales of a bluish gray color, which have lent themselves easily to the structure imposed upon them. There have been produced in these shales a series of divergent anticlines and synclines which, though complicated, are traceable

across the white barren hills. At Shale Point there is an outcrop of coarse granitic sand containing much gypsum and stained through several tints of lavender to brown. The shales in the vicinity are rather soft, light in color, and contain hard calcareous yellow concretions sparingly. A similar bed of sandstone occurs in the shales about 1 mile south of Alfonso's. At one point this appears to be an interbedded sandstone, but at another it as certainly cuts across the strike of the shales and has probably been pressed into its position as a result of folding. Two miles southeast of Ravens Pass a great mass of dark-brown to pinkish, rather coarse sandstone, striking about S. 40° W., cuts through a prominent hill to and slightly beyond the summit. The sandstone has a jagged contact with the shale and is evidently of the same nature as the dikes already described. Reference to the section northwest of Alfonso's, described in the Monterey discussion (p. 58), will give an idea of the character of the Santa Margarita(?) formation south of Bitterwater Creek, since this portion is an extension of the south arm of the Packwood anticline which swings toward the east near Alfonso's camp.

Another area of Santa Margarita(?) extends along the summit of the range immediately southwest of McDonald's ranch for nearly 3 miles. It has been preserved in the axis of a prominent syncline and represents only the basal portion of the formation. The peculiar yellowish to brown calcareous zone which is characteristic of the formation north of McDonald's is found here also.

AREAS IN TEMBLOR DISTRICT.

For nearly 9 miles southeast of McDonald's ranch, the shales of the Santa Margarita(?) are not certainly present, since the eastward swing of the folds controlling the distribution of the shales undoubtedly places the series considerably east of the lowest foothill exposures, so that they there lie completely buried beneath the superficial deposits of the valley margin. In sec. 29, T. 28 S., R. 20 E., the basal shales of the series emerge from beneath the valley floor as the uppermost beds of a monocline which dips about 50° NE. The soft lavender to white diatomaceous and semiporcelaneous shales are beautifully exposed in the smooth bare hills extending from here parallel with the McKittrick road as far southeast as the canyon along the northwest side of the Gould Hills, where their angular nonconformity with the overlying McKittrick formation is very marked. Strong evidence of petroleum impregnation has been found in both the gravels and sands above the Santa Margarita(?) in this vicinity, and in the Monterey shale below, although the diatomaceous beds themselves are comparatively free from evidence of petroleum content. At the Gould Central wells in the SE. ¼ sec. 7, T. 29 S., R. 21 E.,

such is not the condition, however. There a small area of soft light diatomaceous shale of supposed uppermost Santa Margarita age is heavily charged with asphalt, while the sands of later age, which completely surround the shales, are likewise well impregnated.

Between Gould Hills and Frazer Spring, the McKittrick gravels, sands, and travertine deposits have so far encroached upon the older formations that the Santa Margarita(?) has been completely buried.

AREAS IN McKITTRICK DISTRICT.

General statement.—While the three areas exposed in the McKittrick oil district will, for convenience, be treated separately, it must be remembered that these are but the exposed portions of an undoubtedly continuous zone of shales which, south of McKittrick, swings southwest toward Crocker Spring and thence, without visible break, along the flank of the range as far as Spellacy Hill. The popular misconception as to the existence of a "break" between McKittrick and Midway appears to have arisen from the present lack of development in the Crocker Spring region, coupled with the peculiar structural conditions. In a later discussion of the structure facts will be stated which indicate the continuity of the Santa Margarita(?) from McKittrick to Midway. (See pp. 69–71.)

McKittrick area.—The largest and commercially most important of these areas appears about three-fourths of a mile west of Frazer Spring as a narrow strip upon the axis of a wavy anticline which plunges toward the northwest. Just southeast of the spring it becomes very wide, extends along the foothills through the developed McKittrick territory, where it is nearly 1½ miles across, and thence passes along the northeast flank of the prominent ridge in secs. 28, 33, and 34, T. 30 S., R. 22 E., as a more and more restricted zone, until almost at the middle of the N. ½ sec. 34 it disappears beneath the later accumulation of sand and gravel of the McKittrick formation. Within or adjacent to this area of the Santa Margarita(?) lie all the producing wells of the McKittrick field. A thorough understanding of the lithology and complex structure of the district is, therefore, essential to any consideration of future economic development.

At the northwest extremity of the area the shales are diatomaceous and include siliceous and thin yellowish layers. A curious feature noted southeast of Frazer Spring is that where these shales have been exposed to weathering agencies, as on open slopes and ridges, they appear considerably harder than in fresh cuts. The brick red to crimson stains in the shales, and at the base of the overlying McKittrick in the bluffs just east of the road near Frazer Spring, are probably due to gypsum and to the oxidation of hydrocarbons that have risen along the fractures of the anticlinal axis in the shales at this point.

The general character of the shales of the Santa Margarita(?) formation at the north end of the McKittrick field is shown in the small canyons in the N. ½ sec. 13, T. 30 S., R. 21 E. Here the shales weather white and yellowish, but show a purplish to chocolate-brown color on the fresh surface, due to the complete impregnation with oil. The shale is mostly diatomaceous, although some layers approach the semiporcelaneous condition. The rocks here are strongly contorted and the structure is by no means clear. Semiporcelain and soft shales with dark-brown calcareous layers are underlain by thinly banded dark (except on weathered surface) brown diatomaceous shales, somewhat punky, much folded and crushed.

In the more closely folded portions of the area, especially where the shales have been fractured to any degree, there are deposits of brea or even of petroleum about the orifices of live springs, and these indicate conditions favorable to the concentration of the oil content of the rock.

The general physical character of the shales throughout the area does not vary greatly, except that in some places, usually not far below the base of the McKittrick, the shale becomes more or less gypsiferous. It has also been noted that the more punky, less resistant shales occur where structural activities have been pronounced, as along anticlinal axes and in fault zones.

With the exception of a few very thin bands encountered in some of the wells, and a doubtful lens south of the Providence (Dabney) lease, no sandstones have been found intercalated in the Santa Margarita(?) here.

From the northwest corner of sec. 29 southeastward, the extent of the area is controlled by a strong anticline, and along this portion of the structure there is a most instructive display of the conditions governing the accumulation of oil. While the axis of the fold lies wholly within the Santa Margarita(?) it is flanked on both sides by the sands and gravels of the McKittrick formation, which dip away from it at angles varying from 30° to 60°. The shales of the Santa Margarita(?) are of the usual diatomaceous character and exhale a rather pungent petroleum odor from the freshly broken brownish surface. At some points, especially along the contact with the McKittrick on the south side of the anticline, the shales are so pulverent that the foot sinks several inches into the apparently firm surface. This material resembles lycoperdon powder in physical appearance. While this particular phase is extreme, it suggests the general character of the shale along the anticline. In sharp contrast, however, are certain harder yellowish calcareous layers, which weather to a rough surface and break into fragments that often cover the whole slope below such an outcrop.

Less than one-fourth mile due south of the Dabney (now the Providence) headquarters, and just east of the Midway road, is an isolated hill of grayish sandstone which appears to be a closely appressed syncline of McKittrick formation folded into the underlying Santa Margarita(?). Immediately south of this hill and parallel to it is a small lens of fine-grained brownish sandstone about 18 feet thick, which is apparently interbedded in the vertical shale, but shows at one place that it has been either pushed or sifted into fractures which cut across the bedding of the inclosing shale. The lens contains small shale inclusions. It has the peculiar oblique and more or less angular jointing common to sandstone dikes, and shows on the weathered surface a semiconcretionary structure. If this small area is a sand-filled fracture, the source of the material is obscure. The sandstone is well impregnated with oil. One-half mile east of here and north of the axis are similar masses of sandstone, but their relation to the shale is much clearer. At this point the anticline is overturned toward the northeast so that the sandstone, which is roughly parallel to the bedding of the shales, dips very steeply southwest. Its contact with the shales, especially on the south, is very irregular, and indicates that the surface of the shales must have been pitted and honeycombed before the sands accumulated. Irregular masses and lenses of shale within the sand itself are harder to explain, but may be fragments fallen from an overhanging bluff of shale during deposition of the sand upon a weather-beaten and precipitous rocky shore. The presence of an irregular scattering conglomerate of dark porphyry, schist, quartz, and granite pebbles at the base of the sandstone further emphasizes the likelihood of such an origin. Above the sandstones (to the northeast) are conformable beds of rather soft greenish to cream-colored argillaceous shales of McKittrick age, and hence it is practically assured that the sandstones are the basal beds of the post-Santa Margarita(?) formation. They continue to the southeast along the flank of the fold for nearly 2 miles and form an important oil-bearing bed.

There are several phases of oil accumulation in the Santa Margarita (?) of the McKittrick area. Black, hard threads and stringers of pure bitumen penetrate the shales at many places along cracks which are usually roughly parallel to the bedding. Live asphalt springs or "bubbles" carrying small quantities of gas and saline water are not unusual, especially along the anticlinal axis, and in conjunction with these the mode of growth of a brea deposit in all its stages may be studied. The impregnation of gravels, sandstones, and shales and their subsequent leaching under the influence of weather is common. The remarkable structural conditions which

control the distribution of paying quantities of oil in this field, especially at its north end, will be discussed in a later chapter.

Telephone Hills area.—The northeastern base of the Telephone Hills in Ts. 30 and 31 S., R. 22 E., is defined by a normal fault which has brought the Santa Margarita (?) up against the overlying gravels and sands of the McKittrick formation. There is thus exposed on the northeast face of the Telephone Hills a block of Santa Margarita (?) diatomaceous shales, beginning at the gulch in the northeast corner of sec. 31 and passing beneath the McKittrick formation 3 miles southeast. It is nowhere more than one-half mile wide. Except at the northwest end, where conditions are locally reversed, the relations of the shales to the overlying gravels are best exposed in the gulch southwest of the pesthouse, in sec. 32.

Although there is no surficial connection between this area and that at McKittrick, the two are certainly correlated and are but the exposed portions of a single mass, the true character of which is masked by the overlying formations.

Area near Crocker Spring.—A roughly oval area of very diatomaceous massive white shale is exposed between Crocker Spring and the Santa Fe tank house along the axis of a prominent anticline which here plunges southeast. The shales of this area are well exposed in the gulches leading into that running north of the tank house, and at some points are difficult to distinguish from those which are interbedded with granitic bowldery lenses north of the tank house. The relations between the purely diatomaceous shales and the more arenaceous type with which the bowlder beds are associated is masked by the overlying McKittrick or later beds, and by the folding and minor faulting to which all the sediments have been subjected.

AREA IN MIDWAY DISTRICT.

This zone of diatomaceous shales is defined as beginning at Crocker Canyon, in sec. 18, T. 31 S., R. 22 E., although it is really a part of the last area described. It extends southeast along the Temblor Range at an elevation between 1,700 and 2,200 feet to the NE. ¼ sec. 34, T. 32 S., R. 23 E., a distance of fully 12 miles. It lies above and in apparent conformity with the Monterey shale that makes up the bulk of the range, and below the gravelly beds of the McKittrick formation, the eastward dipping beds of which define the margin of the Great Valley. The difficulty of fixing the base of the Santa Margarita (?) has already been referred to. Equal difficulty has been experienced in trying to define its upper limits, because of the intercalation of the purely diatomaceous beds, referable in themselves to the Santa Margarita (?), with coarse cobble and sandy lenses

typical of McKittrick sedimentation. There is a gradual diminution of the diatomaceous beds upward in the series, and at one horizon which is persistent along the face of the mountains the McKittrick conditions are emphasized in a thick zone of very heavy granitic bowlders, with occasional great blocks several feet in diameter. This conglomerate has been assumed to be the base of the McKittrick and is so mapped and described. The main mass of the Santa Margarita(?) is a northeast-dipping monocline of creamy and pinkish diatomaceous shales, which, except toward the base, are quite free from calcareous layers. It maintains a thickness of about 900 or 1,000 feet throughout the distance, but, because of the local character of the coarser beds in the series, individual shale beds vary considerably in thickness. Local unconformities at the base of the McKittrick, resulting in overlap of the blocky loose bowlder beds upon the underlying shales, produce an appearance of greater or less thickness in the outcrops of the shales.

The following generalized section from the top downward is based upon several meanders across the Santa Margarita(?) southwest of Midway:

Section of Santa Margarita (?) formation southwest of Midway.

	Feet.
Upper portion of soft heavy-bedded diatomaceous shales, creamy to flesh-pink in color (often containing flakes of biotite mica and layers of granitic gravel and sand)	500±
Zone of gray granitic sandstone layers varying locally to gravel and conglomerates of schists and granitic rocks	100–300
Calcareous and diatomaceous shales approaching Monterey shale in appearance	200±

Near the middle of the east side of sec. 18, T. 32 S., R. 23 E., a soft brownish diatomaceous shale varying to hard nearly black flinty layers is in places heavily charged with bitumen. The shales are overlain by McKittrick granitic conglomerate, and just at the contact the joint cracks of the shale are filled with native sulphur, the crystals of which are small but well formed. Considerable gypsum, stained dark by sulphur, is found in this vicinity.

The remarkable conditions under which the shales of the Santa Margarita(?) formation and the beds transitional into the McKittrick formation must have been deposited call for some comment. It is clear that the purely organic beds, since they contain little or no material of detrital origin, could only have originated far from shore or in deep water along the face of a steep escarpment at a distance from the influence of shore currents or of inflowing waters. It is equally clear that the coarse, usually subangular granitic bowlders and blocks which lie in immediate contact with or as lenses in the organic shales indicate conditions of deposition utterly dissimilar.

Few of these blocks could have been transported by the measure of present-day evidence in the same region much more than 6 or 8 miles. Some of them, 12 or 15 feet in diameter, could hardly have been moved so far unless on a very steep gradient and by torrential volumes of water, which dumped their loads unassorted at the first convenient place. Such a condition is surely in sharp contrast with the evidence of tranquil accumulation of organic remains in the adjacent shales. This change did not happen once only, but many times, and it is difficult to conceive of the land and drainage conditions during the period. Except at one point, where a small mass of granitic rock has been faulted up into the Monterey and Vaqueros near White's camp, no granitics are exposed along the Temblor Range. The nearest known source for the bowldery lenses, then, is the Mount Pinos Range, which is fully 25 miles distant from the nearest exposures. The conformity between the Monterey shale and the Santa Margarita(?) does not suggest that the Monterey existed as a mountain range during Santa Margarita(?) time. If the granitic conglomerate was derived from the Mount Pinos Range through the agency of torrential streams, the existence of such a range as a part of the old Mount Pinos Range must, however, be assumed. There still remains the possibility of the bowlders having been carried by moving ice, which, with its load of morainal material, originated in a possibly much higher Mount Pinos Range. No striæ or other evidence of glaciation have been found on any of the blocks or cobbles in the series, however. Further knowledge of the Coast Ranges, especially in the Cuyama, Mount Pinos, and Tejon regions, will perhaps explain the problems which the Santa Margarita(?) and lower part of the McKittrick formation in the Midway district present.

It is practically certain that between the southeast extremity of the area just described and that lying south of Maricopa and Pioneer the series is continuous, although it is nowhere exposed, owing to the overlap of the McKittrick formation upon the Monterey.

AREA IN SUNSET DISTRICT.

The zone of Santa Margarita (?) in the Sunset district stretches for about 3½ miles along the hills back of Pioneer, and bears the same relation to the adjacent Monterey shale and the McKittrick formation as in the Midway district. At its northwest end the shales occupy a syncline, which flattens into a steeply northeastward dipping monocline about 1 mile west of Pioneer. The shales are diatomaceous and contain some calcareous layers. At the top of the series there are beds of sandstone, which probably are the equivalent of the granitic cobbly beds back of Midway. The following section was obtained in the gulch south of Pioneer.

Section of Santa Margarita (?) formation south of Pioneer.

	Feet.
Brea and travertine in creek bottom	10–50
Fine white organic shales with thin sandy layers	100
Brown, well-bedded, medium-grained granitic sandstones, at some points conglomeratic	200
White and yellowish limy organic shales	1,000+
	1,300±

Elsewhere in the vicinity, layers of coarse sandstone 15 to 30 feet thick, interbedded with minor amounts of white, thin-bedded, diatomaceous shale, make up a thickness of 600 to 800 feet at the top of the Santa Margarita (?). Evidences of petroleum are common along the upper horizons of this shale and are especially well developed in the base of the McKittrick formation, which rests unconformably upon them.

BITTER CREEK AREA.

The most southerly area of Santa Margarita (?) studied lies in the S. ½, T. 11 N., R. 24 W., upon both the east and west forks of Bitter Creek. The details of a part of the section in this area, obtained 5 miles southwest of Maricopa, upon the west fork of Bitter Creek, are as follows:

Partial section of Santa Margarita (?) formation on west fork of Bitter Creek.

	Feet.
Soft light terra-cotta granitic sandstones, which carry *Pecten* and *Ostrea*, indicative of Santa Margarita age, 6 feet from the top	12
Coarse granitic conglomerate, with interbedded gray and brown irregular sandstones	125
Brown and gray sand, well bedded and tending toward concretionary structure in middle	12
Granitic conglomerate and sand, larger cobbles 6 to 8 inches in diameter	12
Coarse pebbly granitic gray sand, well bedded and grading up into an overlying conglomerate bed	10

Eastward the terra-cotta granitic sandstones grade into a contorted and faulted series of pinkish to dark-brown sandstone, brownish to blackish shale, and a large quantity of shale breccia and conglomerate derived from the adjacent Monterey. The whole series is much discolored by petroleum and sulphur. Springs carrying sulphur are common a quarter of a mile above the forks of Bitter Creek.

In the hills immediately east of the forks of Bitter Creek the Santa Margarita (?) consists of soft white shale with interbedded bowldery layers and fine yellow calcareous zones. This Bitter Creek area lies within the zone of the San Andreas fault, and is consequently very greatly disturbed. No effort as yet has been made to study the detail of structure there.

AREAS EAST OF HAZELTON.

About 2 miles east-southeast of Hazelton the Santa Margarita (?) soft diatomaceous shale, thoroughly saturated with heavy oil, outcrops in two or three isolated patches. These are shown on the map

as brea, owing to their important hydrocarbon contents. The shale here stands on end, is very plainly and thinly bedded, and shallow wells sunk into it have yielded commercial quantities of oil. (See pp. 191, 192 for description of development here.)

AREAS IN CARRIZO DISTRICT.

A reconnaissance in portions of the Carrizo Plain region has shown the existence of areas of Santa Margarita (?) there, and it is probable that future work in the southwest part of the region under discussion will reveal other areas.

AREA NEAR GARCÍA'S RANCH.

The gravels and sands of the Carrizo Plain at its northwestern end have been sharply trenched by Carnaza Creek in its course to San Juan River, and there are exposed in consequence a series of beds which have been identified as Santa Margarita (?). They are considerably folded and exhibit west of García's place the following section from the top downward:

Section of the Santa Margarita (?) formation near García's.

	Feet.
Alternating beds of hard and soft fossiliferous light-gray granitic sandstone	350
Reddish sandstone and conglomerate, more or less incoherent, with an oil sand at base	500±
Concretionary white shale at base of series or possibly of Monterey age	50+
	900±

Between García's and San Juan River the series is prominently developed and contains at many places light sandy fossiliferous layers. Where the La Panza Valley enters that of San Juan River, fossiliferous sandstones occur in light-colored bluffs, and here some of the beds appear to have been duplicated by faulting. The Santa Margarita (?) extends southeast of García's to the corner of the township, and from a width of about 3 miles tapers off to about a mile wide at its southern extremity. The uppermost beds in this vicinity are hard fossiliferous sandstones. These rest upon less resistant gravels and form the summit of the prominent synclinal hill ending in sec. 36, T. 29 S., R. 17 E. A section in the beds of this hill is as follows:

Section of the Santa Margarita (?) in sec. 36, T. 29 S., R. 17 E.

	Feet.
Hard granitic fossiliferous sandstone	100
Pinkish gravel	300
Gray sandstone and gravel underlain by pinkish gravel	600
Bed of *Ostrea titan* and *Pecten estrellanus*	50
Basal gravelly and sandy beds	300
	1,350

The local character of the Santa Margarita(?) formation, so well shown in the Midway region, is further emphasized by this section. Instead of the diatomaceous beds, common in the northeast flank of the Temblor Range, the formation here contains gravels and sands.

AREA NEAR VISHNU WELL.

This area extends along the west slope of the summit of the Temblor Range for about 4 miles in T. 32 S., R. 22 E. The beds here also are different from the series elsewhere. The exposure so closely resembles the huge blocky granitic conglomerate typical of the McKittrick formation to the northeast that earlier determinations placed it in that formation. Later, however, fossils of either middle or lower Miocene age were found in it, and upon lithologic and stratigraphic evidence the possibility of its belonging to the lower Miocene was eliminated. The structural conditions here, as elsewhere near the San Andreas fault, are complex, but the series appears to occupy a syncline, which has been faulted along its axis so that for a portion of its length the upthrown arm of the fold has been completely removed from the underlying Monterey.

IMPORTANCE WITH RELATION TO PETROLEUM.

Much that was said concerning the relation of the Monterey formation (lower middle Miocene) to the petroleum of the district applies equally well to the Santa Margarita(?) formation (upper middle Miocene). The organic matter contained in the latter is believed to be the source of much of the oil accumulated in the overlying McKittrick beds, and for this reason the presence of the Santa Margarita(?) or the Monterey under the McKittrick is believed to be prerequisite to the productivity of the latter. The Santa Margarita(?) shale is more likely to exhibit its petroliferous character than the Monterey, probably owing in part to its later age and less altered character. The Santa Margarita(?) is oil-bearing only in a small degree, but productive wells have been drilled into it in the eastern part of the Sunset district. Oil is also occasionally derived from shale of the Santa Margarita(?) formation in the McKittrick district. In the Devils Den district the Santa Margarita(?) overlies the oil-bearing Vaqueros sands, and a knowledge of the thickness and structure of the former is necessary in order to properly draw conclusions concerning the probabilities of obtaining oil from the latter at any particular point.

McKITTRICK FORMATION (UPPER MIOCENE).

GENERAL STATEMENT.

Unconformably above the Monterey and Santa Margarita (?) formations and flanking the Temblor Range upon both sides throughout much of the McKittrick-Sunset region lies a series of gravels, clays, and sands which have been in large part correlated with the Jacalitos,

Etchegoin, and Tulare formations of the Coalinga district.[a] It has been found impracticable at this time to differentiate these formations, and whether they can ever be satisfactorily differentiated in this district is a question. Hence they have been classed together as the McKittrick formation, from the town of that name, near which (one-half mile to the south) the formation is typically exposed. As mapped in the Carrizo district the McKittrick formation may include some Santa Margarita. The formation includes practically all of the deformational beds above the Santa Margarita(?) formation, and so is widespread upon the flanks of the Temblor Range. It includes beds of upper Miocene, Pliocene, and Pleistocene age. Breaks in the continuity of the beds are largely the accidental results of erosion, and since the unit is roughly uniform throughout, there is little reason for making areal separation in describing it. Two broad separations are possible, however, one including the areas upon the northeast, the other those upon the southwest slopes of the Temblor Range, adjacent to, and in fact including, parts of the Carrizo Plain.

With the close of the Santa Margarita(?) epoch, the conditions which produced the local coarse sedimentation in that formation became more widespread and persistent. There must have been a far bolder relief in this part of the Coast Ranges than during the early middle Miocene, and it is possible that during part of the upper Miocene (McKittrick) time the range was sufficiently elevated to prevent the existence of marine conditions.

Climatic and land fluctuations produced variations in the character of the sedimentation, and there is evidence even of entire cessation of deposition locally. Broadly considered, the deposits grow finer toward the top of the series, which is evidence of the rapid degradation or subsidence of the mountains that were the source of the deposits, or else of a change in the conditions producing precipitation.

AREAS ON NORTHEAST FLANK OF TEMBLOR RANGE.

Introduction.—The most northerly exposure of the McKittrick formation is that along the Lost Hills, which lie about 12 miles east of Point of Rocks, far out in the San Joaquin Valley. A somewhat similar but less well-defined area is that beginning at Shale Point and extending southeast almost to Santos Creek, at a distance of between 3 and 4 miles from the main foothills. South of Santos Creek the beds are exposed in the foothills, and from McKittrick the area broadens so as to include, if the thin Pleistocene cover be disregarded, all of the hilly region between McKittrick, Midway, Pioneer, and Buena Vista Lake and Buena Vista Slough.

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[a] Bull. U. S. Geol. Survey No. 398, pp. 96-154.

Lost Hills area.—While the evidence is not absolutely conclusive, the Lost Hills Range, which rises about 200 feet above the surrounding plain, is believed to be an anticlinal fold of such recency that its original form, except for the erosional scorings upon the surface, has not been lost. On its northwest end there are exposed moderately hard coarse granitic sands containing shale fragments up to 2 inches in diameter. Cobbles of granitic rock were found with these sands less abundantly. The sands are stained a peculiar brownish to yellow color by sulphur, and it was noted that ignition of the sulphur, accompanied by a slight hissing sound, was produced in some places by the blow of a hammer.

Just south of this exposure, considerable gypsum exists as crusts and veinlets in the soft sandy beds, and is sufficiently abundant elsewhere to be characteristic of the lower beds exposed in the Lost Hills. Yellowish clays are interbedded with the sand at some places, but the dips are so low that no great thickness of the formation is exposed. In sec. 11, T. 26 S., R. 20 E., the summit of the ridge is double, a condition probably due to the repetition of beds upon either side of the anticlinal axis, which may lie between the ridges. The general appearance of the beds here suggests a dip of perhaps 3° upon the northeast side and of even less upon the southwest. Upon a small spur in the SW. ¼ sec. 19, T. 26 S., R. 21 E., is the "Gas Bubble," a small well-rounded knob, which is believed locally to be the result of intumescence of the salts or expansion of vapors contained in the beds. While it is true that an unusual deposit of light-brown to blackish material, resembling certain forms of hydrocarbon, exists here, there is no further evidence of anything unusual. The upper portion of the "Gas Bubble" is a horizontal bed of greenish yellow shaly clay. This is underlain by gypsiferous yellowish clays, and a careful examination of near-by outcrops of the same beds failed to show any differences in level which might indicate an uplift in the clays at the "bubble." It would appear more logical to explain the "bubble" as a residual of erosion which owes its existence to local induration.

The gravels and clays of the Lost Hills extend southeast from the highest part of the ridge for about 4 miles, and finally merge with the later nondeformational gravels of the plain.

There is no evidence by which the age of the beds exposed in the Lost Hills can be determined. They probably belong to the McKittrick formation, but may possibly be of later Quaternary age.

Antelope Hills area.—No structure whatever is evident in these hills, but their existence at such a place with the longer axis across the drainage lines, yet parallel to the major folds of the region, suggests a structural origin for them.

The material exposed is a loose gravel of dark metamorphic rocks mixed with coarse sand. Except for the facts above noted, the whole area might be as readily mapped with the late Quaternary as in the formation under discussion.

Region southeast of Media Agua Creek.—Between Media Agua Creek and the hills east of Carneros Spring there are a number of small isolated buttes of a travertine-cemented conglomerate, the pebbles and cobbles of which are largely of Cretaceous and Miocene rocks. These conglomerates rest unconformably upon both the upturned Monterey and the Santa Margarita. Some of them are certainly of Quaternary age, while others are almost as certainly much older. They have all been included in the McKittrick on the map (Pl. I). An elongated area southeast of Santos Creek and about a mile out in the plain consists of white cross-bedded sands containing shale fragments and some granitic and metamorphic pebbles. In sec. 27 the same beds contain coarse waterworn granitic pebbles in an arkose sand, and at one place on the southwest slope of the hill there is a hard limestone layer. The general dips here are at angles of 30° to 35° NE.

The local character of the formation is well exposed in a canyon on the north side of the Gould Hills. The section is as follows:

Section of McKittrick formation in secs. 2 and 11, T. 28 S., R. 20 E.

	Feet.
Very coarse wash of Cretaceous or Eocene bowlders	300±
Fragmental beds of calcareous nodules derived from Monterey, some granitic and metamorphic pebbles with sandy layers	1,700−
Clayey shale and basal conglomerate	100+
	2,100±

This is an interesting section, since it shows very clearly an unconformity high up in the series beneath the coarse material derived from the pre-Miocene rocks and another at the very base of the series where there is a strong angular nonconformity with the underlying Santa Margarita (?). In every view of the Gould Hills from the south or southwest, even at a distance of 4 or 5 miles, this unconformity is plainly visible where the later formation swings across the west end of the hills.

Salt and Temblor creeks have long been a source of travertine, and much of the flat below the mouths of these streams has been built up by the addition of such a deposit. At many places the travertine is almost pure lime; elsewhere it cements gravel and sand, and so might be classed with Pleistocene deposits. There is clear evidence at certain points in the vicinity, however, that the beds have been folded by the same stresses which have produced structures in the older rocks, and this, coupled with the difficulty of separating them from the

certain McKittrick beds in the region, has determined their inclusion with the latter.

An interesting phase of the McKittrick is found on the hill about three-fourths of a mile southwest of Frazer Spring. Here fragments of Monterey shale only very slightly rounded, and the binding material also, are chalcedonized to such a degree that the matrix is almost indistinguishable from the included bits of shale. This condition is due either to local spring action or to ancient stream cementation, such as that noted at Temblor. Arnold and Anderson have discussed similar occurrences upon White Creek near Coalinga in a recent paper,[a] and to this the reader is referred.

About 3 miles east of Temblor ranch a fold, which is probably an extension of the great Temblor structure, involves the monocline of McKittrick flanking the foothills, and from the southeast corner of sec. 33, T. 29 S., R. 21 E., gives it an anticlinal structure. The fold is closely appressed and fractured along its axis, so that the natural conduits thus produced have afforded an opportunity for the escape of petroleum into the basal shale breccia of the upper beds. Deposits supposed to be of this nature are to be found on the part of the ridge almost at the center of the NW. ¼ sec. 32.

At Sheep Springs, about 1 mile south of the last-mentioned locality, the basal beds of the formation are highly siliceous and appear as a prominent faulted reef, which is particularly well exposed on the north side of the gulch where the springs are. The accumulation of travertine breccia can be readily seen at and below the outlet of the water.

On the south face of the hill, near the west line of the NW. ¼ sec. 12, T. 30 S., R. 21 E., beds of an impure limestone containing molds of *Lymnæa*, a fresh-water snail, were found. This is significant, since it indicates the fresh-water origin of this portion of the formation, which near by contains a quantity of recemented siliceous angular shale fragments.

From this point southeastward the McKittrick formation is intimately associated with the oil-bearing beds of the McKittrick district, and a close resemblance between the outcrops of this and the Santa Margarita(?) formation in portions of the field, together with the close and overturned folding and thrust faulting in the developed territory, has made the McKittrick region probably the most geologically complicated oil field in California.

Just north of the dry lake on the west line of sec. 13, T. 30 S., R. 21 E., the McKittrick rests with rough conformity upon the Santa Margarita (?), on the flanks of a steep but normal anticline, while a short

[a] Arnold, R., and Anderson, R., Conglomerate formed by a mineral-laden stream in California: Bull. Geol. Soc. America, vol. 19, pp. 147-154.

distance northeast the older beds have been overturned to the northeast and were truncated somewhat before the later gravels were deposited. The McKittrick beds consist here of rounded pebbles and cobbles of granite, quartzite, black metamorphics, and white shale, from one-half inch to 5 inches in diameter. Lenses of dark-colored sands, showing evidence of former impregnation with oil, are intercalated with the conglomerate, and the whole dips at angles of 30° to 40° NE.

In the eastern part of the SW. ¼ sec. 12, T. 30 S., R. 21 E., gravelly sands of the McKittrick formation are overturned against the Santa Margarita(?), and this exposure marks approximately the northwest limit of a condition, to be discussed later, which profoundly affects the occurrence of oil in the district. Conditions which suggest overthrust faulting between the Santa Margarita(?) and later gravelly and sandy beds have been noted 1½ miles west of McKittrick. Near the extreme edge of the SE. ¼ sec. 19 of the McKittrick township structural conditions appear to be normal.

The contacts between the formations in these localities are sharp, but elsewhere, as in sec. 10 of the same township, near Kincaid's camp, the Santa Margarita (?) is very gypsiferous and pulverulent, so that the weathered surface almost exactly resembles that of the McKittrick. Yellowish limy cobbles and shale fragments strew the surface of both formations, so that at a distance no distinction is possible, but close examination shows that in the later series there is a great variety in texture, color, and size of the calcareous cobbles, since they are purely derivative. The smaller shale fragments of the McKittrick are usually slightly rounded, while those which have loosened in place preserve their sharp edges longer. It is usually possible to differentiate the Santa Margarita (?) and McKittrick formations where actual outcrops can be found. The McKittrick has been pretty generally removed from the Monterey and Santa Margarita(?) in the developed field, but remnants here and there indicate a former extension of the rocks between the marginal exposures south and west of McKittrick and those extending into Santa Maria Valley.

These marginal exposures do, in fact, join around the end of the southeast plunging structure near the old Belgian (now Temblor-McKittrick) Oil Company's wells. The area of McKittrick just northeast of the Santa Margarita (?) lying northwest of the wells is much faulted, and at places appears to have been fractured and then filled with sand which afterwards became heavily charged with asphaltum. Asphalt dikes of this character in sec. 27, T. 30 S., R. 23 E., were among the first of the deposits to be worked in the San Joaquin Valley. A section from the mouth of the canyon in the NE. ¼ sec 28, about one-half mile east of the Dabney (now Providence) property,

toward the southwest traverses the beds of the McKittrick upon the northeast arm of the McKittrick anticline. The succession is as follows:

Section of McKittrick formation 1 mile southeast of McKittrick.

	Feet.
Soft sandy or clayey beds and coarse soft sandstones below	380
Coarse-grained pink granitic sand with numerous water-worn shale fragments up to 3 inches long	55
Soft sandstone with occasional layers of shale fragments, also brown sandstone and fine scattered shale fragments	35
Hard gray sandstone, some shale pebbles, occasionally brownish and apparently oil stained	80
Greenish and brownish clay shale with thin layers of interbedded sandstone	64
Clay shale and sandstone	18
Brown and pink coarse sandstone with shale fragments, also thin partings of shale, at some points stained by oil, and clay-filled mud cracks	145
Coarse, thick-bedded, incoherent sandstones with numerous shale fragments.	190
Largely shale and clay, alternate hard and soft layers; some sandstone and shale fragments; chocolate, pink, yellowish, and brown (color due to oil impregnation)	290
Green and brown shale with interbedded yellow sands, dark-brown and heavily charged with oil	300±
Water-worn shale fragments forming a fine conglomerate	395
	1,862−

The basal beds of the McKittrick formation in the hill one-half mile south of the Dabney Oil Company's headquarters consist of coarse sands with gravelly layers. Just above this is a bed of granitic, quartzitic, and other hard pebbles which is overlain by clay shale. Numerous *Pecten eldridgei* Arnold occur in the soft sands next to the coarse basal bed.

One-half mile southeast of the old Monarch wells, near an anticlinal axis, reddish exposures of the McKittrick formation consist of thin granitic and quartzitic pebbly beds with light-yellow and whitish clays, all impregnated with petroleum. Near the Belgian wells and along the southwest side of Shale Basin the formation is of greenish clay in which are intercalated thin layers of fine sandstone and calcareous yellow layers harder than the clay.

Some of the basal McKittrick beds are notably gypsiferous, and workings exist in nearly horizontal pulverent clayey beds in sec. 30, T. 30 S., R. 22 E., where, just south of the road, the impure gypsum has been packed for shipment as a fertilizer. No active work was in progress when the place was visited by the writers. The formation in this locality is of much the same character as that southeast of the Dabney headquarters.

In the gulch extending east from the Santa Fe tank house in sec. 17, T. 31 S., R. 22 E., the appearance of beds included for the present with the McKittrick formation is different, and along this gulch are exposed innumerable small faults, in general striking northwest and

southeast, which dislocate yellowish, poorly stratified, earthy beds that resemble the finer facies of Quaternary delta material. These layers, although affected by faulting and folding, are not in conformity with the gravelly sands and clays of the usual McKittrick type. It is possible that they may be the equivalent of the heavy bowlder beds in the Gould Hills described on page 77.

The curving range of lower bare hills north and northeast of McKittrick owe their existence to the development of two well-defined anticlinal structures in the gravelly sands and the clays of the McKittrick formation. In the NW. ¼ sec. 6, T. 30 S., R. 22 E., soft yellow and grayish sandstones, at some points sulphur stained, are interbedded with thin layers of light greenish and bluish clays. Judging from the sump of an old well in this vicinity, similar and coarser granitic sands predominate to a considerable depth, the lower sands showing strong impregnation with oil.

The Elk Hills are the eastern extension of the hills just described, and are likewise a structural uplift of the McKittrick formation. The general resemblance of the beds here to one another and the low dips of the strata make a measurement of the thickness only approximate. The following section was obtained on the southwest side of Elk Hills:

Section of McKittrick formation in the Elk Hills.

	Feet.
Coarse gravel of considerable variety of rocks, maximum cobbles about 6 inches diameter	175
Soft, light yellowish-brown sandy clay with white efflorescent alkali	50
Gravel of equal parts of shale fragments and mixed colored pebbles; maximum diameter, 3 inches	50
Soft light-yellowish clays like the second bed above	40
Gravel of shale fragments and colored pebbles, the latter predominating; 4-inch pebbles maximum	100+
Soft yellowish-brown sand with occasional streaks of shale and mixed pebbles.	75
Soft yellowish-brown sand with greenish drab clay stratum at base	60
Gravelly sand and clay, upper 15 feet of which is stained light purple by alkali; both sand and clay are very soft	100
	650

Although the section is crossed by a sharp fold, it is hardly more than a crinkle and does not affect the succession of the beds. The lithology of the Elk Hills is practically summed up in the section above, since, except locally, there is very slight variation in the character of the beds. Not a single fossil has been found in these hills, but the position of the beds exposed here is believed to correspond nearly with the upper portion of the McKittrick section at Midway.

The Buena Vista Hills, like the Elk Hills, are of structural origin and owe their existence to an anticlinal uplift which has folded the

gravels and sands of the McKittrick formation into both sharp and low broad arches, the topographic continuity of which has been broken by streams draining into Buena Vista Valley. The beds displayed through the folding are similar to those of Elk Hills, and are fairly well exposed in the gulch running northeast across the northwest portion of T. 31 S., R. 23 E. Two anticlinal axes cross this channel almost at right angles, and at the more southerly gray clays, somewhat gypsiferous, are interbedded with yellowish gravels and whitish limy layers. The fold flanking Buena Vista Valley is steeper and shows yellowish sand with pebbly zones upon its southwest arm. About 1½ miles northeast of the gulch last mentioned, upon the north arm of the same fold flanking Buena Vista Valley, the following partial section is exposed:

Partial section of McKittrick formation on northeast flank of Buena Vista Hills.

	Feet.
Heavy conglomerate of granite, shale, and quartzitic pebbles	1,040
White calcareous layer, free from impurities	10– 20
Greenish clay and sand	450– 500
	1,500–1,560

The lowest beds of this section are probably as far down in the series as any exposed in either the Elk or the Buena Vista Hills.

In the southeast end of the Buena Vista Hills the broader geologic features are observable from the high point east of the old road in sec. 15, T. 32 S., R. 24 E. The uppermost beds here are sands and gravels, which form the rather prominent northeast face of the ridge and thence swing east and north to form the outer beds of the plunging anticline which is the main structure in these hills. Below the gravels are less conspicuous beds of yellow sand and finer pebbly material, in places stained somewhat by petroleum.

The oldest beds exposed in this vicinity lie in sec. 11 at and immediately west of the road. These are low croppings of a medium-grained sand which has been very heavily impregnated with oil. It lies exactly at the broad axis of the low but extensive anticline which affects the McKittrick formation here, and is an excellent indication of deposits of petroleum beneath. From here northward along the road the beds dip gently toward Buena Vista Valley, and, as elsewhere in this region of low dips, appear to merge with the undisturbed gravels and sands of the depressions.

An important area of McKittrick formation from 1 to 3 miles wide occurs along the northeastern base of the Temblor Range from Crocker Spring southeastward to and beyond Maricopa. Within this area are found all the productive wells of the Midway and Sunset districts, and it is believed that almost without exception the oil reservoirs drawn upon are a part of the McKittrick. One exception is the deepest sand in the St. Lawrence and adjacent wells in the

central part of the Midway field; this sand is said to be of Santa Margarita (?) age. The relations of the McKittrick formation to the underlying Santa Margarita (?) have already been described (p. 75). The upper limits of the McKittrick are, at many points, indefinite, because of the close lithologic resemblance to ordinary cross-bedded or roughly assorted delta sands and gravels. Elsewhere the change from deformed to flat-lying beds marks the contact between this and the Recent deposits.

At the northwestern end of the Midway area the beds are of coarse granitic conglomerate at the base and sandy and gravelly above, with tilted and faulted beds of an earthy character east of the Crocker Spring road. Associated with these heavy basal conglomerates are white diatomaceous beds, which are locally important, as in sec. 1, T. 32 S., R. 22 E., where erosion upon an anticline and the corresponding flat syncline has exposed the shale at the surface over a considerable area. The same bed is traceable northwest for over 2 miles and southeast for about a mile upon the southwest arm of the syncline, and extends to within 1¾ miles of Midland along the anticlinal axis.

Many of the sandstone beds in the lower half of the McKittrick formation are well charged with petroleum, and it has been observed that those adjacent to the included diatomaceous shales are the richer. Many such lenses of impregnated sandstone are in the southwest portion of sec. 35, T. 31 S., R. 22 E.

A typical section of the formation is that from the Andrews well in sec. 15, T. 32 S., R. 23 E., southwest to the anticlinal axis about a mile distant. In general the following succession was obtained:

Section of McKittrick formation in T. 32 S., R. 23 E.

	Feet.
Superficial gravel dipping gently northeast and overlying beds of sand and gravel unconformably	25
Gravelly granitic sands with thin clayey layers	200
Light-green coarse and fine granitic sandstone with thin clay layers; also thin hard layers	75
Fine well-bedded yellow granitic sand with thin harder seams	100
Coarse gray sand with plentiful shale pebbles	200
Coarse and fine gray sand and greenish shales with shale pebbles	160
Gray and white sandstone with many shale pebble layers	100
Light gypsiferous sandstone with shale fragments; contains white porcelain shale layer	120
Oil sands with granitic cobbles at base, sands dark brown and coarse	50–80
Brown diatomaceous shale, strongly impregnated with oil (at anticlinal axis).	150
	1,230

The diatomaceous shales at the base of this section represent the uppermost beds that show the influence of the fluctuating Santa Margarita (?) conditions; the lowest beds of the McKittrick are exposed about three-fourths of a mile southwest of the anticlinal

axis, where they bend upward on the south arm of the complementary syncline. Here the much coarser conglomerates are intercalated with fine diatomaceous shales, stained pinkish brown by petroleum.

In the vicinity of Spellacy Hill, both the anticline and the syncline that deform the McKittrick beds broaden and flatten considerably, so that the anticline has produced the dome in the developed field and the syncline the broad high flat to the southwest. The level beds exposed upon the margin of this flat are poorly stratified soft yellow sands, containing bits and pebbles of Monterey shale and of granitic rocks. In the south half of sec. 35, T. 32 S., R. 23 E., these beds begin to show the influence of deformation in a gentle northeast dip, which steepens on the knobs in the southwest quarter of the section and exposes the following beds at the base of the McKittrick, which here rests unconformably upon the Monterey.

Section of McKittrick formation in sec. 35, T. 32 S., R. 23 E.

	Feet.
Gray sand with granitic and quartzite gravel, averaging about 4 inches in diameter. The large granite blocks so characteristic of this horizon back of Midway are absent	25+
White flinty shale streaked with purple, composed of bits of opalized shale with vitreous fracture	40
Zone of sulphur-colored shale	20
Layer of gray sandstone	10
	95+

The less blocky character of the upper bed here indicates a change in the conditions which produced the heavy granitic conglomerate at the same horizon toward the northwest.

In the hills which, crescent-like, partly encircle Monarch, Maricopa, and Hazelton, the McKittrick is well exposed, and owing to the several well-defined folds which have been truncated by erosion on Bitter Creek, the succession of beds is easily seen. Because of these folds, however, a full section of the series is difficult to get. The uppermost beds in this vicinity are probably those exposed in the low hills about 2½ miles east and 2 miles northeast of Monarch, where the following succession was noted:

Section of upper part of McKittrick formation 2 miles northeast of Monarch.

Yellowish sands grading into gravelly material	300 to 500 feet.
Granitic, metamorphic, and shale pebbles in an arkose sand	
Yellowish earthy beds with calcareous streaks; some pebbles	
Fine white shale pebbles; granitic and metamorphic pebbles in lesser number; matrix soft and gypsiferous	

The bedding of these layers is very poorly preserved, but the dip appears to be 6° to 8° NE.

The broad major anticline which extends southeast across sec. 34, T. 12 N., R. 24 E., exhibits the following partial section:

Partial section of McKittrick formation in sec. 34, T. 12 N., R. 24 E.

	Feet.
Pinkish granitic conglomerate, color due to decomposition of iron-bearing minerals of the granite	100
Yellow and drab sands, drab clay layers, and hard sandstone bed near top	100
Drab clay and sand	100
	300

Due west of Maricopa the foothills are composed of thin-bedded, coarse, pebbly granitic sandstones with layers in which shale fragments are numerous. The basal beds here do not carry large bowlders, as they do farther northwest. In general, the series here has a peculiar greenish-drab color, except on those fresh exposures which may have been stained brown by oil. Relations at its contact with the underlying Santa Margarita (?) in this vicinity are usually obscure, owing to folding and faulting.

A fairly complete section of the formation in the Sunset field is based on a well log, and is as follows:

Section of McKittrick formation in the Sunset field.

	Feet.
Yellow clay	102
Conglomerate	54
Sandstone	8
Blue clay and sand	35
Yellow clay	107
Blue clay	36
Hard layer ("shell")	6
Blue clay	14
Hard layer	5
Clay and gravel	14
Blue clay and sand	194
Water sand	3
Blue clay and shale with water	102
Blue clay	12
Hard layer	4½
Blue clay	5½
Oil sand (shale and sand stringers)	23
Blue clay	23
Oil sand	5½
Shale	13
Hard layer	4½
Clay and sand	18
Oil sand	5½
Very hard layer	8
Gravel and clay	16½
Shale and oil sand	32
Bluish clay (contains fossils)	
Hard layer	
Gravel, shale, and thin hard layers	41
Hard layers	1
Oil sand	30
	923

It is evident that the well on whose log this section is founded penetrates only a portion of the series, unless there is a considerable thinning of the beds between there and Spellacy Hill, a condition for which no evidence has been found.

Two and one-half miles west of Maricopa pink to dark-brown conglomerate with maximum bowlders 1 foot in diameter overlies a clay bed, which in turn extends unconformably across the basal yellow and drab sandstones of the McKittrick, across the Santa Margarita(?), and even encroaches upon the Monterey. This lack of conformity within the McKittrick formation is characteristic and possibly marks an erosion interval at some points in the upper Miocene or Pliocene.

South and southeast of Sunset, the McKittrick formation is typically developed and the basal sandstone beds are heavily impregnated with oil. The following section, exposed in the canyon in the E. ½ sec. 28, T. 11 N., R. 23 W., indicates the lithology of the formation:

Section of McKittrick formation in sec. 28, T. 11 N., R. 23 W.

	Feet.
Sandstones, stained by sulphur and oil	60
Thin-bedded sandstone	10
Thin-bedded brown and yellow sands (color due to oil and sulphur) and thin-bedded sandstone	60
Medium-grained oil sand with shale fragments	90
Thin-bedded sandstone with some pebbly beds, at some points stained yellow with sulphur	55
Thin-bedded brown sandstone, oil impregnated	40
Conglomerate of sandstone pebbles and cobbles with maximum diameter of 18 inches	55
Oil seepage in medium-grained granitic and micaceous sand	60
Coarse gray granitic sand charged heavily with oil. Sulphur water escapes from spring in sand, but little oil accompanies it	75
Brown oil-stained and yellow granitic sand	30
Granitic sand, shale and sand pebbles with diameter of 3 inches	85
At axis of anticline flat beds of granitic sand stained yellow, and pink gypsum oil and sulphur.	
	620

The canyons both east and west of that in which the above section was made are identical with it in structure and general lithology, although the oil seepages are less marked toward the northwest. There is every reason to believe that the possibilities for oil development in the flats north of this neighborhood are good. From this locality the McKittrick formation extends eastward along the south end of the San Joaquin Valley, at least beyond the mouth of San Emidio Creek, and to a point near Grapevine Canyon, where it is well exposed in a section along Pleito Creek. It is probable that the heavy granitic gravels skirting the Tehachapi Range at the extreme south end of the valley will be correlated with this series.

AREAS ON SOUTHWEST FLANK OF TEMBLOR RANGE.

At Carter's ranch, which lies within Palo Prieto Pass at the west edge of the region studied, the McKittrick formation is well developed in a broad area which is undoubtedly a part of the deposits extending northward to the mesa country east of the Salinas Valley. This area extends southeastward along the summit and southwest slope of the range to where Bitterwater Creek cuts across the mountains at Sumner's ranch; beyond that, with the exception of two residuals on the summit and a single small doubtful area near the road 3 miles southeast of McAllister's ranch, it lies only upon the southwestern slope of the range, as far as sec. 15, T. 31 S., R. 21 E. Here gravels and sands believed to belong to the McKittrick formation are involved in the intense faulting which has pushed a small block of pre-Cretaceous granite up through all the overlying sedimentary beds and brought it into contact with late Miocene deposits at the summit of the range. Small isolated areas of gravelly and sandy deposits occur along the top of the range from here southeast to the neighborhood of Vishnu well, where a larger deposit of exactly similar nature, containing Santa Margarita fossils, is found.

It is very evident that the problem of harmonizing the difference in age between these summit deposits and those extending along the lower flank of the range from the Palo Prieto region, where the gravels are probably of McKittrick age (upper Miocene), is a difficult one. A long study of the relations in this much faulted region will be necessary before the solution can be reached; for the present it can only be stated that the McKittrick formation, particularly on the summit and west slope of the Temblor range, as drawn on the map, probably includes beds of Santa Margarita age.

The McKittrick has been traced along the margin of the Elkhorn Plain only as far southeast as sec. 27, T. 32 S., R. 22 E., although it may extend farther, and there are excellent proofs in the gulches tributary to Carnaza Creek that the series underlies the Carrizo Plain, at least in its northern portion, as a broad geosyncline. It has not been found, however, upon the southwest margin of the Carrizo Plain as a part of the deformational series. At present no data are available as to the depth or character of the filling of the Carrizo Plain at its broadest part.

LITHOLOGY OF BEDS ON WEST SLOPE.

The broad, rolling, grassy slopes of the summit of the range east of Carter's ranch is composed of gravels and grayish to greenish clays which are usually too soft to afford good exposures except at the heads of gulches or upon the steep landslide faces along the zone affected by the San Andreas fault. West of Carter's a low hill has been cut by the county road, and at this point a soft, light-colored arkose sand-

stone with pebbly layers is exposed. The hills on the southwest side of the Palo Prieto Pass are composed of southwestward-dipping sands and gravel in which the pebbles are of Miocene sandstone, Franciscan rocks, and white siliceous shale. Such is the character of the formation in most of the region between Carter's and Sumner's ranches. Good exposures are shown in sec. 1, T. 28 S., R. 17 E., where there are regularly bedded, thin, white, and brown to bluish clays containing some gypsum. The bedding has been locally affected by landslides. Lower in the series in the main gulch, just above the house at Sumner's ranch, considerably crushed, gravelly, and light-colored arkose sandy beds are exposed. These are stained a rich pink, probably by iron derived from the granite sand and pebbles of which the beds consist.

On the west side of the Palo Prieto Pass, just south of Sumner's and west of the road, there are bunchy exposures in the McKittrick of a calcareous travertine which appears to have developed along fractures of a much crushed sandstone containing large granite cobbles. On the opposite side of the creek are the vertical and overturned beds of the Monterey which have been faulted upward against the later formation.

The relations between the McKittrick and the earlier sediments are well exposed in this region, and particularly upon Bitterwater Creek northeast of Sumner's. The greenish clays and gravels of the lower portion of the McKittrick lie unconformably upon both Cretaceous and Franciscan, but have been faulted against the Monterey and Vaqueros except possibly at one point, where they appear to lap around the Monterey at its northern extremity.

All the broad country of rolling hills south of Sumner's consists of soft, bluish-green clays and gravels of the McKittrick, which have in general a gentle southwest dip, except along the zone of the San Andreas fault, where they are complexly involved with the shattered shales of the Monterey. Such are the conditions southeast of Wolfort's, where a much folded, probably anticlinal block of Monterey has been wedged into the gravels of the McKittrick formation, which are locally upturned by the movement. No attempt has been made to express anywhere along it the detail of this faulted contact. Step faults within the McKittrick make an estimate of its exposed thickness impossible.

The series is well exposed at and just southeast of the mouth of San Diego Creek in upturned beds of fine, bluish clays, with some layers of shaly gravel, all in striking contrast with the yellowish Monterey shale against which they have been faulted. Between there and White's camp there was a marked and sudden transition in the conditions under which the series were deposited. Instead of clays and fine sands there is a heavy granitic conglomerate inter-

bedded in coarse sandy layers, which suggest intermittent torrential conditions much like those indicated southwest of Midway. These beds are well exposed in the canyon northeast of White's, where there is a fault which cuts off the base of the McKittrick and throws it against crushed yellow sandstones and brown carbonaceous shales supposed to be of Vaqueros age. The local succession of beds in this vicinity is as follows:

Section of McKittrick formation in the vicinity of White's camp.

	Feet.
Bluish and buff arkose sands containing rounded pebbles	900
Coarse sands containing beds of heavy granitic and schistose bowlders especially prominent at about 100 feet	2,000
Heavy granitic bowldery and blocky lenses in loose sands	800
	3,700

This section is typical of the series from here southeastward to and beyond the old Vishnu well in sec. 22, T. 23 S., R. 22 E.

Southwest of White's camp, parallel to the main range, but distant from it about a mile, are the Panorama Hills. At two points in these hills fossils indicative of the Jacalitos formation have been found, but as yet no attempt at differentiation has been made. A section across these hills, about 1 mile south of White's, is as follows:

Section of lower part of McKittrick 1 mile south of White's camp.

	Feet.
Granitic conglomerate	40
Brownish-yellow soft sand	70
Fossiliferous, slightly concretionary layer	10
Soft brownish-yellow sands	100
Fossiliferous layer	8
	228

IMPORTANCE WITH RELATION TO PETROLEUM.

The McKittrick formation is the principal oil reservoir of the developed fields of the McKittrick-Sunset region, its basal conglomerates and sand yielding practically all of the product of the McKittrick, Midway, and Sunset fields. The oil is believed to originate in the Monterey and Santa Margarita(?) formations, and at least part of it to migrate across the line of unconformity between these and the overlying porous beds of the McKittrick. In these fields the zone of impregnation varies in thickness from 200 to 1,000 feet or more above the base, most of the commercially productive sands lying within the lower 200 feet. Besides the evidences of petroleum found in the McKittrick in the developed fields, the group offers indications of oil in the Gould Hills, the Buena Vista Hills, and the region east of the developed Sunset fields. It is upon such evidence that the conclusions are based that productive wells will be obtained in the McKittrick formation in areas other than those already developed.

A study of the thickness and structure of the McKittrick is necessary before proper predictions can be made concerning the probabilities of the occurrence of and depth to oil-bearing beds at the base of this group of rocks.

UNDIFFERENTIATED MIOCENE.

Upon the southwest slope of the Temblor Range, in the center and southeast part of T. 32 S., R. 22 E. the western portion of T. 12 N., R. 25 W., and in secs. 4 and 5 of T. 11 N., R. 25 W., the relations of the Miocene sedimentaries is not clear and it has been found necessary to group them tentatively under the heading "Undifferentiated Miocene." This area is shown with a separate pattern symbol on the map (Pl. I). Within the area thus patterned it is believed that the Vaqueros, Monterey, and Santa Margarita (?) formations and the McKittrick formation are represented.

QUATERNARY SEDIMENTS.

DESCRIPTION.

To this period have been assigned the sands, clays, soils, and gravels which are the results of relatively recent erosion. Although deformational processes are even yet active in the region, at least along the San Andreas fault, it has been impossible to determine, in the short time available, whether the uppermost of the folded beds belong to the McKittrick formation or to a later Quaternary epoch. The Quaternary has therefore been tentatively made to include only such deposits as do not show the results of folding or faulting. This will exclude all except the modern stream alluvium, the fan materials skirting the range, and possibly some gravel remnants high on the slopes of some of the canyons.

In the smaller canyons the Quaternary deposits are usually thin and have been derived from the immediate drainage basin. Along the margin of the San Joaquin Valley there is the usual type of varied fan material, the result of the coalescence of detritus from a number of sources. These fans slope at slightly varying, but always very low, angles toward the Great Valley. In spite of the low slopes and flat surfaces, huge bowlders are often carried out on these fans for considerable distances from the mouths of the canyons by the mud-saturated torrents, which result from waterspouts during certain periods of the year. As illustrative of the size of some of these bowlders, of those lying on the low, flat slope of the valley edge near the road in the northeastern part of T. 28 S., R. 19 E., one lying 2 miles from the mouth of the nearest canyon is over 9 feet in diameter. In general, the material of the fans is finer the farther it lies from its source.

Probably the most important fact brought out in the investigation of the Quaternary is that, while each of the greater features of the region is of purely structural origin, they have at many points been greatly modified by erosion. Instances of this are observable in the Devils Den district, where Wagonwheel Mountain is entirely isolated by Quaternary gravels from its structural continuation in the Barton Hills, and where the prominent syncline of Sawtooth Ridge, in Antelope Valley, is cut off around its southeast end by Quaternary deposits. Many other instances of erosional modification of structures are available.

An excellent example of a somewhat different phase of Quaternary accumulation is that of the Santa Maria Valley, whose drainage area is restricted. The rainfall here is slightly greater than that on lower portions of the range, and, judging from the smooth contours of the canyons leading into the valley, especially from the west, is not of the torrential nature common in this region. Much of the shale detritus in the canyons is angular, having slid in from the sides, and the bits of rock pack together rather loosely and serve as an absorbent of the rain as it falls, allowing it to percolate into the similar, though more widespread, deposits of the Santa Maria Valley. Settlers at the mouths of some of these canyons state that only after the very hardest winter storms is there even a slight surface run-off. The main valley has thus become a natural storage reservoir, the spillway of which is a group of springs a short distance north and northwest of Maddux ranch. Successful wells have been sunk in this vicinity to take advantage of these water gravels. The Quaternary deposits of the Santa Maria Valley are probably not over 100 feet thick at their deepest points.

Another, the travertine phase of Quaternary deposition, has been previously referred to and in part described as belonging to the McKittrick formation. Many of the streams, particularly those flowing across calcareous portions of the Monterey shale, carry considerable lime in solution, and in the lower reaches of the stream courses, either after the waters have become overloaded or evaporation has become a greater factor, the lime is deposited with the wash gravels and sands to form a more or less firm conglomerate, which hardens upon exposure to the air. As the channels deepen, remnants of these conglomerates are retained at varying heights above the latest deposits. Such are the rather poorly cemented bowldery croppings lying with great unconformity upon the Monterey shale on either side of the main McKittrick road about 2½ miles southeast of Carneros Spring. Other examples of these travertine conglomerates are found in the shale basin southeast of McKittrick and in the canyons in sec. 32, T. 30 S., R. 22 E.

IMPORTANCE WITH RELATION TO PETROLEUM.

Except as a local lodgment place for asphalt and heavy oil in certain portions of the McKittrick-Sunset region, the Quaternary deposits are important economically with relation to the oil industry only as a mask covering the oil-bearing and related formations. As such, the Quaternary hinders the working out of the structure, a knowledge of which is necessary in properly forecasting the occurrence or nonoccurrence of deposits of petroleum in many localities throughout the region.

IGNEOUS ROCKS.

Besides those rocks of igneous origin already described in connection with the Franciscan formation (pp. 32–34), there are only two groups of areas of such rocks in the whole region studied. One of these, containing diabase, is on the southwest side of Carrizo Plain, near Syncline Hill, and has already been referred to in the discussion of the Monterey. It is only necessary to state further that it is of the common type of intrusives found elsewhere throughout the Coast Ranges in the Monterey and Vaqueros formations. The rock is a dark, fine-grained, rather soft diabase, which, though intrusive, is very limited in its effect upon the surrounding sedimentaries.

The other area lies upon the summit of the Temblor Range in the SE. ¼ sec. 23, T. 31 S., R. 21 E., just northwest of a lone cabin. The rock here is associated with rocks of Vaqueros (lower Miocene) age. Some of the material is rather scoriaceous, and the whole is undoubtedly a remnant of some flow which has since been almost wholly removed by erosion. A hand specimen of the rock, where fresh, shows an even medium grain and a dark greenish-gray color. The upper portion of the basalt of this area is honeycombed with cavities, some of which show secondary deposits of calcite or a yellowish crystalline deposit, the composition of which is unknown. This area, which is almost too small to map, is the only one of Tertiary igneous rock which has been found in place in the Temblor Range.

STRUCTURE.

In the foregoing discussions of the formations, various details of structure have been referred to, but on account of its importance in connection with the origin and accumulation of petroleum the structure is here more amply described.

GENERAL COAST RANGE RELATIONS.

The Temblor Range, which is the most southeasterly of the several mountain groups comprising the Coast Ranges of California west of the San Joaquin Valley, occupies a unique position with reference

to the great forces controlling structural conditions in California. It is skirted along its southwest side by the great world structure line known in the United States as the San Andreas fault zone. The range projects at its southern end into the complicated country including the Tehachapi and Mount Pinos ranges, which are the topographic expression of a new set of forces brought into play at the south end of the San Joaquin Valley. In consequence of the conflict of stresses, the south end of the Temblor Range has suffered severely and a complete unraveling of the complex folding and faulting produced will be a large undertaking.

RELATION BETWEEN STRUCTURE AND TOPOGRAPHY.

There is a very close relation in the McKittrick-Sunset region between topography and structure. This preservation of structural forms is due in part to the aridity of the climate, which has prevented the obliteration of the main features, although not always of the minor folds, and in part to the recency of some of the processes which have affected the folding and faulting. Particular examples of this survival of original structure follow:

Pyramid Hills as far south as Dagany Gap form a single steep-sided anticlinal structure, which retains its form for a number of miles toward the north into the Coalinga region.

Lost Hills, which have already been described under the discussion of the McKittrick, are without doubt due to an anticlinal uplift in the originally flat surface of the Antelope Plains. They are of such recent development that erosion has not yet succeeded in destroying the original arching form.

By far the best examples in the region are the Elk Hills and the Buena Vista Hills, each of which ranges is really a single major structure with subsidiary crinkles on either arm. Seen from a distance, Elk Hills, if the very youthful but numerous drainage lines be eliminated, must present much the same appearance that it did when formed.

Syncline Hill, near the northwest end of the Carrizo Plain, is an excellent example of a syncline which has preserved its form despite the degradation of the surrounding country to a depth of 300 feet or more.

The topographic effect of faulting in the McKittrick-Sunset region is even more striking than that due to folding, especially in the San Andreas zone. Palo Prieto Pass is purely a structural depression, which, except at its southeast end, is modified but little by erosion. It shows every evidence of being a line upon which long-continued faulting has taken place. Even minor features, such as slight differences in elevation between blocks lying within the fault zone, have been preserved. All of the foothill region southwest of the Palo

Prieto Pass and its southeastern continuation, the upper course of Bitterwater Creek, has been, if not profoundly, very completely faulted, usually along lines parallel to the major displacement. In consequence there have been developed narrow tilted blocks of the upper McKittrick formation, between which have been produced elongated closed depressions, often containing ponded waters. Such faulted depressions are very common in the region. Probably the best examples of such small step faults and their corresponding tilted blocks and depressions are found at the Poso Ortega Spring, about 1½ miles southwest of Sumner's ranch.

By far the most prominent escarpment in the whole region is that which separates Elkhorn Valley from the Carrizo Plain. Although low and narrow, it is practically straight, and is the surface expression of a geologically very recent displacement upon the San Andreas fault zone. Because of its topographic prominence and structural origin, it has been called the Elkhorn Scarp.

Practically all the topographic features along the southwest slope of the range show the direct influence of the San Andreas fault. Even at a considerable distance out in the Carrizo Plain the steplike succession of blocks on the slope of the range is plainly visible.

The faults at the summit and upon the northeast slope of the range are less effective in modifying the topography, although they, too, have indirectly done their part. Faults in the Antelope Valley have undoubtedly been instrumental in giving an opportunity for more rapid erosion there. A portion of the course of Salt Creek north of Temblor ranch may also owe its origin to a fault zone.

GENERAL STRUCTURE.

As in the Coalinga district, the major structures of the McKittrick-Sunset region do not exactly parallel the Temblor Range, but cut it obliquely toward the southeast at a very low angle. The angle is sufficient, however, to give to the range an en échelon topography which is evident in such spurs as that of Shale Point, Gould Hills, Elk Hills, and Buena Vista Hills. The eastward swing of the folds is accentuated in the southern portion of the range, and is due to the greater dominance of the stresses which formed the east-west block of the Tehachapi and Mount Pinos ranges.

The long period during which deformation has been taking place in the region is amply shown in the series of marked unconformities which separate formations and in the overlaps of one series upon another. The merely local character of some of the disturbances is often evident, as at Raven Valley, where the shales of the Santa Margarita (?) rest directly upon the Cretaceous, while but a short distance north, in the Barton Hills, several thousand feet of Eocene, Oligocene (?), and Vaqueros sediments separate them. This clearly indicates a remark-

able differential elevation which became equalized at the beginning of Santa Margarita (?) deposition.

The most recent general depression of the region was that during which the gravels and clays of the McKittrick formation were deposited. Judging from their presence upon both flanks of the Temblor Range, and directly upon the Cretaceous sandstones at the summit of the mountains, it is clear that a free sweep of water must have existed where the north end of the Temblor Range now is, during a period just preceding the Quaternary. The great Quaternary uplift to which in part the Sierra Nevada owes its elevation, and which marks the beginning of the present era of rapid erosion and consequent ruggedness of peak and canyon, also produced a marked change in Coast Range conditions. The deposits of late McKittrick age were upraised at least 2,500 feet and considerably folded and ruptured, especially along the margin of the uplifted block; that is, on both flanks of the Temblor Range.

A final proof of the present instability of the region is found in the existence of the San Andreas fault zone, along which movements have occurred within historic time.

STRUCTURAL DETAILS.

Some of the larger folds and faults of the region will be described briefly, although it is believed that the maps accompanying this report are sufficiently self-explanatory for the greater number of these features.

Syncline north of McGovern's ranch.—North of McGovern's ranch is a syncline in the Monterey and Vaqueros formations, with reference to which the point to be emphasized is that it is sharply truncated by a northwest-southeast fault which brings a block of serpentine directly against the end of the structure.

Raven Valley anticline.—The axis of the Raven Valley anticline, a large normal fold which involves a broad area of Tertiary and Cretaceous rocks, is occupied by intimately folded Cretaceous beds, in which the main structure is obscured. This old core has resisted the later stresses, and consequently the shales of the Santa Margarita(?), being less stolid, have responded by the production of a number of subsidiary folds upon the northeast arm of the anticline. These are particularly well developed between Bitterwater and Packwood creeks.

Santos anticline.—The Santos anticline, a fold in the Eocene southwest of Santos's lower ranch, is unimportant, except in showing that north and south faulting in this vicinity is more recent than the folding. This is clearly indicated in the offset of the axis toward the south for a short distance between two faults which extend across the Monterey well up toward the shales of the Santa Margarita(?).

Cross folds near Temblor ranch.—In the foothills immediately north of the Temblor ranch houses there are a couple of local synclines and an anticline which involves Tejon, Vaqueros, and Monterey beds. The axes of these structures radiate eastward from a point about a mile northwest of Temblor, and extend transverse to the usual trend of the folds. They are evidently the result of stresses developed along a nearly north and south line in connection with the faulting upon Salt Creek. Other folds in the vicinity have been similarly affected, particularly the Gould anticline, which is traceable along the range southwest of Carneros Spring to sec. 22, T. 29 S., R. 20 E., where it swings east and then slightly north of east for a distance of 4 miles before it resumes a southeasterly direction.

Temblor anticline.—The Temblor anticline, despite faulting upon its axis, is one of the most persistent in the region. Its axis is clearly traceable in sandstones from a point on the summit 8 miles northwest as far as the Section Six Oil Company properties, in sec. 36, T. 29 S., R. 20 E., where it plunges sufficiently to allow the Monterey shale to pass around the nose of the fold and occupy both sides of the anticline. From this vicinity southeastward the structure is less clearly developed, but it is believed that the sinuous anticline which extends through Frazer Spring into the McKittrick district is the continuation of this fold.

Sandiego anticline.—The Sandiego anticline, which, except at its southeastern extremity, lies wholly upon the southwest side of the Temblor Range, has been traced about 9 miles. It is more regular than most of the structures near the San Andreas fault zone, and is more profound, since it brings up the Vaqueros sandstone at intervals along the axis. The discontinuous character of these exposures of sandstone indicates an undulatory condition in the axis.

Folds at summit of Temblor Range.—The structurally diverse conditions of the Temblor Range are well illustrated in the region between the summit of the Temblor-Simmler road and the head of Crocker Canyon. The summit is broad here and includes sinuous anticlinal and synclinal structures which vary from normal to overturned and even recumbent positions.

Santa Maria syncline.—The Santa Maria syncline, a prominent structure, originates in the 3,900-foot knob on the summit of the range in sec. 30, T. 29 S., R. 20 E., and from a point 2 miles southeast of there to its southeastern extremity the fold has had a marked influence upon the topography. This is less evident southwest of Temblor, where the axis occupies a flat stretch just below the county road, than it is in the Santa Maria Valley, which is an original structural depression only slightly modified since by erosion. The syncline is somewhat less marked southwest of McKittrick, but probably continues for some miles farther to the southeast.

Folds of McKittrick district.—The structures which have a definite bearing on the oil accumulation in the McKittrick district will be described under the heading "Structure" in the detailed discussion of the McKittrick field (pp. 129–130).

Special structural conditions around McKittrick.—In studying the well logs of the McKittrick region, particularly in the northwestern portion of the field, it was soon found that there was a very unusual disagreement between the surface evidence of structure and that shown at depths of 300 to 1,000 feet in the well logs. Thus, while the structure in the shales of the Santa Margarita(?) formation consists at the surface of a series of closely appressed and overturned folds, the oil sands penetrated by the wells lie in a low northeast-dipping monocline. The diagrammatic section (fig. 2) shown herewith has been drawn to aid in the explanation of what appears to be a very complex structure. It is believed that every other possible explanation has been eliminated, and the following concise statement will endeavor to make clear the only hypothesis that seems to fit the facts noted.

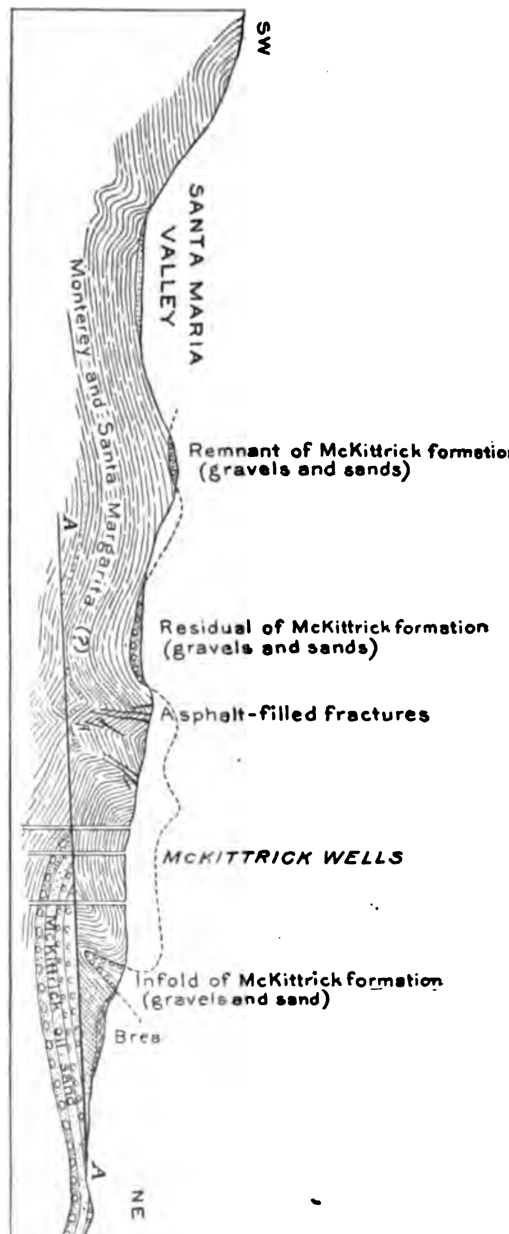

FIGURE 2.—Ideal section at north end of the McKittrick field.

In the first place, it must be assumed that the gravel and conglomeratic sands which carry the oil in this portion of the field are a part of the basal series of the McKittrick formation and that these beds were deposited unconformably upon the shales of the Monterey and Santa Margarita (?) formations. As already stated, there is plentiful evidence of such an unconformity; that the sands encountered in the wells are of McKittrick age is proved by fossils found in many of the wells penetrating these sands. Furthermore, it must be remembered that the oil gravels and sand are similar to the remnants of McKittrick which occur at many points in the McKittrick district, but that beds of similar nature do not occur interbedded in the Santa Margarita (?) or the Monterey in the McKittrick region.

At some late period, geologically speaking, the shales of the Monterey and Santa Margarita (?) formations, with their overlying McKittrick gravels, must have been faulted along a plane making a very low angle with the horizontal, as indicated in the diagram (fig. 2) on the line *A–A*, and the block to the southwest forced above and shoved across that to the northeast, so that part of the McKittrick became buried far below actually earlier shales of the Monterey and Santa Margarita (?) formations. The effect of this movement upon the shale itself was to crinkle it very sharply and produce the folds found to-day in the north end of the McKittrick field. Had this crinkling been the only result of the overthrust, the conditions, while complex, would probably be evident in the field, but in addition the structure was further complicated by two cross faults, one at either end of the overthrust. The most northwesterly of these, the Frazer Spring fault, traverses the shales of the Santa Margarita (?) just southeast of Frazer Spring, and the other, which is less apparent in the field, is believed to run in a northeast-southwest direction across the northwest portion of sec. 19, T. 30 S., R. 22 E. These two faults have effectually prevented the emergence of the gravels of the McKittrick from beneath the overthrust block of shales of the Santa Margarita (?) formation. This has been brought about in the Frazer Spring region by the upthrust of the rocks lying northwest of the Frazer Spring cross fault to an elevation sufficient to bring the McKittrick into its normal relation as an overlap upon the Monterey shale. The result, as seen in the field here, is as follows: At any point east of the Temblor ranch the gravels of the McKittrick dip at varying angles up to about 45° NE. and away from the Monterey shale, on which they rest. This condition is clearly visible to a point about one-eighth mile east of Frazer Spring, where, for a short distance, the fault has produced a confusion in the relations. About one-half mile northeast of Frazer Spring, however, the gravels of the McKittrick are found dipping directly against and beneath an

abutment of the shales of the Santa Margarita (?). This point marks the first definite surface evidence of the overthrust. Unfortunately, except for a few exposures east of Frazer Spring, the northeast margin of the overthrust block lies obscured beneath the Quaternary deposits of the McKittrick Valley, until the peculiar structural conditions of sec. 19, T. 30 S., R. 22 E., connected with this overthrust are reached. In sec. 19 the two major folds (the Shamrock and Dabney anticlines) make a sharp bend toward the southwest from their normal northwest-southeast direction, and this bending, though traceable only a short distance, is very definite. A study of the well logs in this region has shown that the syncline between these two folds is also very sharply flexed and overturned, and that other structures not apparent at the surface, which extend from the northwest, butt directly into the cross folds. No explanation for this remarkable flexing is adequate unless the existence of a fault running northeast and southwest through sec. 19 be assumed. That this fault marks the southeastern limit of the overthrust condition is apparent after study of the well logs, since the group of wells immediately southeast of the fault shows that the oil sands occur on both arms of a recumbent syncline (see Pl. V) which is undoubtedly but one step removed from the complete overthrust known to exist northwest of the fault.

Folds in hills northwest of McKittrick.—Two prominent anticlines, one a section of the Gould anticline, which extends from northwest of the Temblor Valley to the Elk Hills, pass through the hills northwest of McKittrick and control the position of the geologic formations and also, to a less extent, the topography of these hills. The courses of both anticlines are sinuous and reflect the thrust movements of the fault blocks to the southwest. Toward the northern part of the hills the most westerly of the two folds is simple and has an arched top with sides dipping at angles up to 40°. Toward the southeast this fold becomes more closely compressed and possibly faulted. The easterly one of the folds is, on the whole, the more complex of the two, the beds on its flanks being steeply tilted, and in several instances crushed and faulted. Commercial deposits of petroleum occur in the McKittrick beds in these anticlines.

Folds of Elk and Buena Vista hills.—The Elk and Buena Vista hills are of very recent origin. The broadly arching anticlines to which they owe their existence have been traced as carefully as time would permit. The low angles of 5° to 10° at which the incoherent sandy and clayey beds dip makes the exact drawing of the axes with reference to the topography difficult. The two nearly parallel folds which comprise the Elk Hills are probably the southeastern continuation of the Gould Hill anticline and a parallel similar structure.

These anticlines coalesce near the end of the Elk Hills and plunge to the east beneath the San Joaquin Valley.

Similar though less continuously traceable folds are responsible for the Buena Vista Hills. About 5 miles east of the Standard Oil Company's pump station, near Midway, one of these folds begins to plunge eastward, and in so doing terminates the hills along the east line of T. 32 S., R. 24 E.

A broad syncline forms the depression between the Elk and Buena Vista hills, and upon its flanks two sharply buckled anticlines are developed. These latter folds are probably of little depth and have been produced as a result of pressure during the development of the other folds.

Crocker Spring anticline.—The Crocker Spring anticline is a good example of a plunging anticline in the older Miocene sediments. Just northwest of the road to Crocker Spring, in sec. 7, T. 31 S., R. 22 E., the fold makes a steep plunge to the southwest, but about a quarter mile farther in this direction the axis emerges in shales of the Santa Margarita (?) formation, swings toward the east for about a mile, and then again plunges, this time beneath the gravels of Crocker Creek. The unusual nature of this fold is clearly visible from the summit of the ridge in the extreme northwest corner of sec. 7.

Folds in Midway and Sunset districts.—The structures which control the accumulation of petroleum in the Midway and Sunset districts are as follows: The Midway anticline, extending from just northwest of the Santa Fe headquarters northwestward along the margin of the hills for 3½ miles; the Spellacy Hill anticline, first noted in sec. 18, T. 32 S., R. 24 E.; the Thirty-five anticline, which lies just north of Monarch and may be a continuation of the Spellacy fold; and the California Fortune anticline, which extends southeast through the hills of the McKittrick formation west of Monarch and Maricopa to a point three-fourths of a mile south of Maricopa. These folds are described in the discussion of the developed territory (pp. 143, 165).

The west wall of Bitter Creek canyon is of folded Monterey shale, no less than eight structures having been established in this region. Some of these are traceable northwest for fully 18 miles.

FAULTS.

Antelope Valley faults.—Antelope Valley is the focus of dislocations which have been long continued and profound. The course of the greatest of these displacements, an overthrust fault which has pushed the Cretaceous sandstone and shale of the north side of the valley far over the shales of the Santa Margarita(?) formation, is partly buried now by recent gravels, although a slight terrace-like

shelf somewhat north of the median line of Antelope Valley may indicate the fault's position. The steep southern face of Orchard Peak and its ridge is an escarpment developed along two or more subsidiary faults within the Cretaceous. The south side of Antelope Valley is a network of faults, two systems being recognized. The older system extends northwest and southeast, approximately parallel to the folds in the sedimentaries. These older faults are offset by another system of less prominent dislocations having a general north-and-south direction. The actual line of faulting is in several places emphasized by linear clusters of springs which have risen along the fractures developed. Such are those upon the margin of the narrow belt of Franciscan just east and southeast of McGovern's ranch.

It has been found that nearly all the older systems of faults in this region, if projected, converge at or near Polonio Pass, which lies at the apex of Antelope Valley. No reason for this condition has yet been found. There is no doubt that the valley and pass form a depressed area, modified by erosion that has been accelerated in the crushed beds of the faulted zone.

Temblor fault.—Except in the McKittrick district, where faulting plays an important part in the distribution of petroleum, stresses have in general been relieved upon the eastern flank of the Temblor Range by folding. Exception to this must be made with reference to conditions noted upon the Temblor anticline. The axis of this fold is coincident with a fault which has dropped the Monterey of the southwest arm of the fold down against the Eocene of the other arm. South of the Temblor ranch the fault diverges somewhat from the axis and may extend through the obscure region near Sheep Spring and thence along the northeast slope of the hills northeast of Santa Maria Valley to join the faulted block of Telephone Hills.

San Andreas fault zone.—The San Andreas fault zone of intense displacement will be only briefly referred to here, despite its very great importance.[a] The segment of this fault zone included within the region studied extends along the southwest side of the Temblor Range for nearly 80 miles and varies from a few hundred feet to 3 miles wide. This is but a very small portion of a fault zone which has been traced uninterruptedly through California from Point Arena almost to the Salton Sea, a distance of over 600 miles. Along this zone most of the California earthquakes have originated, and it is beyond computation how long the movements had been in progress previous to historic record. These movements have so crushed, sheared, folded, and dislocated the rocks of the whole southwest side of the range that elucidation of structure and, at points, even of

[a] This fault zone is fully treated of in the Report of the Earthquake Investigation Commission upon the California earthquake of April 18, 1906, published by the Carnegie Institution of Washington, D. C., 1908.

the physical character of the rocks is very difficult. The topography produced by the latest movements in this region is unique and interesting. Low ridges on both or one side of elongated depressions, sunken areas in flat land, and great furrows along hill slopes are some of the evidences of the fracturing which occurred, as near as can be determined, in 1857. Definite evidence of horizontal movement has been found in the region, at one point of over 400 feet. Actual measurements of between 8 and 20 feet of such displacement were made at the time of the San Francisco earthquake of 1906, which occurred at and near the northwestern end of the same zone of faulting. These latest faults are mostly of the normal type and are usually parallel or convergent at very low angles.

Elkhorn Scarp is the most striking topographic evidence of the action of the San Andreas faulting. It is undoubtedly due to the dropping down of the Carrizo Plain or the elevation of the Elkhorn Valley about 200 feet. From the upper end of this scarp the fault zone extends into the Mount Pinos Mountains and thence into the San Gabriel and San Bernardino ranges.

WATER SUPPLY.

GENERAL STATEMENT.

All of the McKittrick-Sunset region, with the possible exception of a narrow zone along the highest summits of the Diablo and Temblor ranges, lies within the semiarid portion of inner California. The moisture-laden clouds from the Pacific pass over this region with little interruption by the Coast Ranges, and are precipitated as rain upon the high slopes of the Sierra Nevada far eastward. All of the run-off thus produced is taken up by the larger Sierran streams and is valuble to the agriculture of the east-side deltas. It may be said with practical certainty that not a single stream flowing into the Great Valley from its western margin is perennial. The annual precipitation ranges from 5 to 12 inches, and this is often concentrated into two or three torrential storms during the season.

One of the gravest problems, therefore, confronting those who are striving to develop the petroleum resources of this region is that of water supply, and as a possible help in the solution of this question the following notes made during the geologic study of the region are herewith offered.

SURFACE SUPPLY.

San Emidio Creek.—The nearest perennial stream which might be available to users of water in the region is probably San Emidio Creek, which heads in the San Emidio Mountains and enters the San Joaquin Valley about 12 miles east of Sunset. The normal flow of this stream belongs to the Kern County Land and Water Company,

which makes use of it for irrigation upon its ranch at the mouth of the canyon. Unless unforeseen legal difficulties are in the way, however, it is believed that the storm flow of this stream, if it could be conserved, would be available, especially to the rapidly developing Sunset field. The water is undoubtedly the best to be found in the neighborhood, since its source is in a granitic region sufficiently high to be fed by the winter snows.

Buena Vista Lake.—Buena Vista Lake, the waters of which also belong to the Kern County Land and Water Company, would seem to be another source of fairly good fresh water. This lake lies 291 feet above sea level, and its waters are derived principally from Kern River. The use of this source would entail the construction of pumping plants and pressure lines sufficient to insure a lift of at least 900 feet, exclusive of friction loss. While this would involve the expenditure of a considerable sum, it would doubtless greatly simplify the present vexatious question of water supply if an arrangement agreeable to the owners could be effected.

San Juan River.—A third source which, however, is almost out of the question, is San Juan River, which flows along the southwest side of the Carrizo Plain. The water is said to be of fair quality and if properly conserved could be had in sufficient quantity for the needs of the region. The two greatest difficulties in connection with this source are its distance, between 20 and 25 miles, from McKittrick, and the obstacles which the Temblor and Caliente ranges present in the construction of pipe lines. Whether a gravity line could be built from this river to the oil fields is doubtful. No other possible surface source within a reasonable distance of any of the developed fields is known.

UNDERGROUND SUPPLIES.

In underground supplies are included such sources as might be developed from springs or wells. Unfortunately much of the spring water in the region is inferior in quality, but it is probably all suitable, with treatment at least, for boiler purposes, while distillation makes it fit for drinking purposes. The following localities are cited as affording possible opportunities for water development:

Wells in Devils Den district.—The following data concerning the water wells drilled in the Devils Den district or adjacent regions are of interest:

County water well, south line of sec. 33, T. 26 S., R. 20 E. Struck water at 45 feet; drilled to 160 feet with water all the way. Windmill connection to 130 feet, but found that the well could be satisfactorily operated by pumping from 60 feet.

Tickle well, SW. ¼ sec. 21, T. 25 S., R. 19 E. Struck water at 112 feet in a dug well. No water was encountered in wells on the low ground west of the Tickle well.

Miller well (Cesmat well), NE. ¼ sec. 35, T. 25 S., R. 20 E. Water struck at 270 feet in drilled well. Minor quantities encountered at 136 feet or 140 feet.

Water well, sec. 25, T. 25 S., R. 19 E. No depth given.

Water well, sec. 7, T. 25 S., R. 20 E. Water struck at about 60 feet.

The water in all of the above wells is more or less mineralized and is usually suitable only for stock or certain industrial purposes.

Spreckels Springs.—In the Devils Den region the most notable springs are those which were developed a number of years ago by the Spreckels Oil Company in the southeastern extremity of the Diablo Range. Several springs at the head of a canyon which flows eastward through secs. 23 and 24, T. 25 S., R. 17 E., have been enlarged and the water piped to a wooden tank near the mouth of the canyon, just above the group of camp houses of the company. The total flow of these springs does not appear to be much over a couple of inches, but the water is good and constant in supply. It is stated that over $12,000 was spent in the development of this water.

Cottonwood Springs.—A series of springs in Cottonwood Canyon, but near its mouth, just below the road between Dudley and Cholame, have apparently never been developed, and these would undoubtedly furnish several inches of water in case of need.

Alamo Solo Springs.—At about the center of sec. 2, T. 25 S., R. 18 E., the underflow of McLure Valley is brought to the surface, probably by the shale reef of the Santa Margarita (?) formation, which marks the connection between the two portions of the Pyramid Hills, in a series of slow-flowing springs which are used as a watering place by the stock of the neighborhood. Although the water is apparently inferior, being strong in Epsom salts, it is constant in flow and might be of service during preliminary developments in the region. A somewhat similar spring lying in the NE. ¼ sec. 11, is in midsummer hardly more than a seep. All of the country adjacent to this gap is more or less moist and covered with efflorescent salts, and the alkaline ground water undoubtedly lies but a short distance from the surface. Wells have been sunk in this part of McLure Valley and furnish an alkaline water which has been used with moderate success in drilling in the Barton Hills.

Springs near Annette.—A number of springs along or associated with fault zones have been found in this region. The water is usually excellent, but except in the springs about half a mile southeast of Annette post-office does not generally flow in great quantity. Those just referred to, however, have a measured flow in spring of as much as 10 miner's inches and are used for intensive irrigation upon a near-by ranch. As no oil development has yet taken place in this region, the call for use of the water of these springs is not imperative. None

of them have sufficient volume to pay for transmission beyond a few miles.

Packwood Spring.—A single flow of rather strong sulphur water in sec. 8, T. 27 S., R. 18 E., is the only supply in the Tertiary rocks for a number of miles in either direction along the flank of the range. Although poor, it might serve as boiler water in case of need.

Springs on summit of range southeast of Cedar Canyon.—The summit of the Temblor Range from Cedar Canyon southeast to the Kern County line contains undoubtedly the best springs of the whole McKittrick-Sunset region, both in quality and amount of water. Of these sources Napoleon, Walnut, Los Yeguas, and Santos springs are the most important, and of these Los Yeguas probably has the greatest flow. It rises in a canyon on the McAlester ranch and flows southwestward to form a part of the headwaters of Bitterwater Creek. When visited in August, 1908, a quantity of water entirely derived from Los Yeguas Spring was flowing down the gulch. This water belongs to one of the Henry Miller properties, but is unused except for stock purposes. Walnut Spring is of the same character, but it does not appear to have quite as heavy a flow. The Napoleon Spring taken alone is unimportant as a source. It is believed that if the waters of Walnut and Los Yeguas springs could be combined they might prove valuable in the oil development upon the east flank of the range, to any part of which they could be distributed by gravity. The water of Santos Spring rises in the bottom of a canyon about 2 miles southeast of the McAlester ranch, and while good, is not great in quantity. None of these springs are being used as their importance demands.

Carneros Spring.—A basin hollowed out of the sandstones in the NE. ¼ sec. 5, T. 29 S., R. 20 E., receives a small quantity of fairly good water, which trickles slowly in from the surrounding rocks. Despite its insignificance, this spring is as well known as any in the region, since it is the only potable water near the road between McKittrick and Dudley. For years past it has been in use by the cattlemen and sheep herders of the region, and, to judge from the remarkable pictographs and pottery fragments found among the steep rocks in the neighborhood, was known for untold years by the Indians previous to the coming of the white man. The waters of another spring a mile or two southeast of Carneros might, by combination with it, give a sufficient supply for a small amount of development.

Springs near Temblor.—Springs which are said to have originated during an earthquake in the early sixties flow down the canyon of Temblor Creek. Some of these have been utilized by the ranch, but others remain undeveloped, although the Section Six Oil Company, the properties of which lie a short distance northeast of the ranch house, contemplate piping the waters of these springs to its wells.

Sheep Springs.—Several springs, locally known as "Sheep Springs," flow from beneath the travertine-cemented gravel in the canyon in sec. 4, T. 30 S., R. 21 E., and these join to make a considerable stream used for stock purposes. Judging from the amount of travertine in the vicinity, the water is highly charged with lime. So far as known this water has not been used at any of the oil wells to the east, possibly because of legal difficulties, since the springs belong to the Henry Miller Company.

Springs between Sheep Springs and Temblor.—About a mile north of Sheep Springs the McKittrick formation rests unconformably upon the Monterey shale, and at this line rise several more or less saline springs. The water is inferior both in quantity and quality, but might bear a certain amount of development. So far as known, these springs are not utilized for any purpose.

Frazer Spring.—Of a somewhat similar nature is a spring which lies just west of the McKittrick-Coalinga road in sec. 2, T. 30 S., R. 21 E., at the axis of the anticline at that point. The flow is utilized for stock, and it is doubtful if there is sufficient surplus water for any other use.

Gravels of Santa Maria Valley.—As described previously (p. 91), the gravels of the Santa Maria Valley form a natural reservoir for the storage of such run-off as falls upon the rather limited drainage basin inclosing it. Few of the canyons entering the valley show any evidence of surface flow, and it is believed that probably two-thirds of the precipitation in this region finds its way by slow percolation to gravels in the lowest part of the valley. The natural spillway of this gravel-filled depression is a spring about one-half mile northwest of Maddux ranch, but the available supply has been increased by the sinking of eight wells from 58 to 70 feet in depth. The material in all these wells seems to be a mixture of sand, clay, and small bits of shale very similar to the superficial deposits of the region. The best flow of water in these wells is to be found at a depth of 40 to 60 feet, beneath hard conglomeratic rocks which are probably travertine. While the capacity of the wells has not been measured, it is believed to be between 5,000 and 9,000 barrels a day. The water from these wells is piped about 20 miles through one 4-inch and one 8-inch pressure line and furnishes the greater part of the supply of the Midway field. It formerly retailed at Midway for 21 cents a barrel but is now much cheaper. A well belonging to the Associated Oil Company has been sunk in this same vicinity, but nearer the springs, and this supply is used in and around McKittrick. It is stated that when the wells of the Santa Fe Company are pumping in full capacity the Associated well is considerably lowered.

Hot-water well at McKittrick.—Well No. 5, sunk by the McKittrick Oil Company in the NW. ¼ sec. 18, T. 30 S., R. 22 E., has for several

years past been the source of an immense quantity of warm sulphur water estimated roughly at between 60 and 80 miner's inches. At present the well is not flowing, the cause for its cessation being unknown.

Crocker Spring.—This small spring and another of a similar nature about a mile west in the same canyon are utilized only for stock purposes, but might with a certain amount of development at the springs furnish a small quantity of fairly good water for industrial or other purposes.

Stratton (Oregon-Midway) water well.—This well, the water of which is used in the Midway region and even as far southeast as Spellacy Hill, rises in a well sunk originally for oil in the northeast corner of sec. 7, T. 32 S., R. 23 E. For this region the water is good, and is said to amount to about 100,000 gallons per day, all of which is utilized. A second well was sunk by the same company a few hundred feet northeast for the purpose of developing more water, but none was obtained. No satisfactory explanation for this condition has been found, although it is possible that the water well happened to strike a fracture associated with the near-by anticlinal axis, which the later well missed. No natural sources of water have been noted between Crocker Spring and the southern limit of the region studied, unless the slow water and tar seepage just west of Maricopa is excepted.

Water wells in Sunset region.—Four or five water wells in the Sunset-Monarch region, however, are worthy of mention. Occidental No. 4 obtains its water between 1,450 and 1,550 feet deep in a series of sands. No temperature record is available, but the water is warm. The Arcola water well flows about 3,000 barrels a day of strong sulphur water, with a temperature of 120° F. The Tiger well obtains its water from a zone between tar sands at a depth between 500 and 600 feet. The Fulton well gives about 800 barrels a day from hard sands at a depth of over 1,700 feet. The well of the Northern Oil Company, described in detail on page 184, gives several thousand barrels of warm slightly saline water per day. This water occurs in an isolated sand lens at the top of zone B. All these wells except that last mentioned and the Tiger obtain their water from the sand lenses intercalated in the Miocene shales.

In the NW. ¼ and SE. ¼ sec. 13 are three water wells about which little is known except that the supply is derived from a depth of about 800 feet. Some data upon the quality of certain waters in the Sunset-McKittrick district are given by W. L. Watts.[a]

[a] Bull. California State Min. Bur. No. 3, pp. 90 and 91.

AMELIORATION OF PRESENT CONDITIONS.

The development of the west-side oil fields of the San Joaquin Valley is being retarded at present as much by the lack of proper water supply as by anything else. The Southern Pacific Railroad Company furnishes a small and irregular supply to users at its tracks at the rate of 3 cents a barrel. This supply is hauled in tank cars from a point on Kern River about 40 miles from the fields. Water from the wells in the Santa Maria Valley belonging to the Santa Fe Railway formerly sold for 21 cents a barrel but is now delivered for much less. The water of the Stratton well is sold at 3 cents a barrel. None of these sources are at present sufficient. Any of them is liable to be shut off unexpectedly, and such conditions may be expected to prevail until some large company is willing to investigate the various sources of supply and invest sufficient capital to insure an elastic and permanent water system for the region.

THE OIL FIELDS.

SUBDIVISIONS.

The McKittrick-Sunset region embraces three important and well-known oil districts, the McKittrick, Midway, and Sunset, and three others at present less important and practically undeveloped, the Devils Den, Temblor, and Carrizo Plain districts. In addition, the areas including the Lost Hills, Bitterwater Valley, and the Buena Vista Hills have been segregated as districts to facilitate the discussion of future development. The description of the important fields will first be taken up, after which those in which development is less advanced will be briefly discussed.

UNDERGROUND CONTOUR MAPS.

Explanation.—The contour maps of the McKittrick, Midway, and Sunset fields (Pls. II, III, and IV) show the structure and certain culture, such as towns, section and property lines, wells, and a few roads. The structure in the productive territory is indicated by contours showing the distance above (marked plus) or below (marked minus) sea level of the top of the productive oil zone (zone B of the text). The contour interval is 100 feet. By means of these maps the direction and amount of dip of the strata in the oil-bearing formation may be calculated for any point in the field, and the depth to the top of the productive oil zone may be approximated for a considerable part of the territory.

Use of the maps.—Suppose it is desired to find the probable depth below the surface of the top of the productive oil zone at a point in the middle of the E. ½ sec. 12, T. 11 N., R. 24 W. An examination of the map of the Sunset field (Pl. IV) will show that this point lies

approximately on the underground contour line marked "-100"; that is, the top of the productive zone (zone B) is here about 100 feet below sea level. A close approximation to the elevation of the point may be had by looking up the elevation for the nearest derrick (see list, p. 194), which happens to be Golden West well No. 1, elevation 783 feet, and calculating the difference in elevation, say 20 feet lower, either by the eye or with an aneroid barometer or level; the elevation of the point in question would then be 763 feet above sea level. The distance from the surface to the top of the oil zone mentioned would, therefore, be approximately 763 plus 100 feet, or 863 feet.

Suppose it is desired to find the dip of the beds in the SW. ¼ NE. ¼ sec. 12, T. 11 N., R. 24 W. An examination of the map just mentioned shows that the beds dip a little north of east (or strike a little east of south), and that the dip is about 400 feet for one-fourth mile, or about 30 feet for 100 feet at right angles to the strike. The south and east components of this dip may be calculated by measuring in these directions instead of directly down the dip of the beds, which is always at right angles to the direction of the contours.

Basis of the maps.—The section and property lines of the McKittrick contour map (Pl. II) are compiled from the maps loaned by various oil companies in the field. The locations and elevations of many of the wells were instrumentally determined and furnished by either the Associated or the Kern Trading and Oil Company. Other elevations were approximately determined with an aneroid barometer and the locations approximated by pacing or by plane-table methods. The underground contours are based on an examination of the log of practically every well which had been drilled in this field up to November 20, 1909.

Most of the section and property lines on the Midway map (Pl. III) and many of the locations and elevations of the wells are from a map kindly loaned by the Chanslor-Canfield Midway Oil Company (Santa Fe Railway). Still other locations are from maps furnished by the Kern Trading and Oil, Associated, and Mascot oil companies, and the rest of them were found by pacing and the elevations by aneroid barometer. The underground contours are based on an examination of the logs of practically all the wells drilled in this field up to November 20, 1909. Owing to the greater irregularity of the oil zones and sands in the Midway district and the fewer and more scattered wells upon the logs of which the contouring is based, the Midway map is less accurate than those of the McKittrick and Sunset fields.

The lines and some of the locations of the wells on the map of the Sunset field (Pl. IV) were compiled from maps furnished by various companies, including the Associated, Kern Trading and Oil, and

Standard. The elevations were obtained by aneroid barometer, and many of the locations were determined either by pacing or by plane-table methods.

Difficulties of preparation and degree of accuracy.—After carefully plotting all the logs on a uniform scale it was found that the greatest obstacle to overcome in the preparation of the contour maps was the correlation of the strata from one well to another and from one part of the field to another. The difficulties of such correlations are doubtless familiar to anyone who has tried to work out the underground structure of any of the California fields. The effort has been to delineate on the present maps all the details of structure consistent with the use of the well logs as confidential information, and to supplement these details by showing for the untested areas what seem most likely to be the conditions of underground structure. Within the untested areas the underground contours are of course only hypothetical and are shown by broken lines.

Regarding the degree of accuracy, it may be said that aside from the wells of the Associated and Kern Trading and Oil companies at McKittrick, and certain of those of the Chanslor-Canfield Midway Oil Company in the Midway field, the elevations are only roughly approximate, say, to within 25 feet or less, so that an error of at least 25 feet is liable to occur on this account. The well logs are assumed to be accurate to the usual degree—that is, ordinarily to the length of one "screw," or about 5 feet. The factor of error for the developed territory is therefore small, but will necessarily increase with the distance away from the drilled ground. Future development will add much to the knowledge of these fields and will show the inaccuracies of the contouring as here presented, but it is hoped that the benefits which may accrue to the operators from a knowledge of the general structure of the fields will compensate in a measure for the errors in detail which are to be expected in a map based on incomplete and approximate data.

The section and property lines on the contour maps, as on the general geologic map, are only approximate, and no effort was made to correct any of the inaccuracies of the government surveys.

McKITTRICK FIELD.

LOCATION.

The McKittrick field, as defined in the present report, extends from Frazer Valley, near the north line of T. 30 S., R. 21 E., southeastward for 7 or 8 miles to the northeastern part of T. 31 S., R. 22 E. It includes the low hills between the Santa Maria and McKittrick valleys and the southeastward extension of these hills as far as the northeast corner of T. 31 S., R. 22 E. The proved territory embraces

an area of between 4 and 5 square miles, but future development will doubtless add to it.

GEOLOGY.

OUTLINE OF STRATIGRAPHY.

The formations involved in the geology of the McKittrick field include the diatomaceous shales of the Monterey and Santa Margarita (?) formations, the sandstones, clays, and gravels of the McKittrick formation, and Quaternary gravels, sands, clays, travertine, and asphaltum deposits.

The Monterey consists of between 3,000 and 5,000 feet of hard clay and diatomaceous shale, with which are intercalated hard, dark-brown, calcareous, concretionary layers and occasional hard, coarse, sandstone lenses. The Santa Margarita (?) formation consists of 1,500 ± feet of soft diatomaceous shale, locally silicified to chalcedony, in which are a few fine soft sandstone lenses and layers. The McKittrick lies unconformably upon the Monterey and Santa Margarita (?), and consists of nearly 2,000 feet of soft dark-colored shale, fine to coarse pebbly sand, incoherent pebbly sand and cobbly layers, and possibly, also, travertine-hardened beds. The coarser basal portion of the McKittrick is the productive oil zone of the field, the petroliferous strata being found throughout a thickness of 200 to 600 feet or more. The Quaternary deposits consist of horizontal sands, clays, and breccias, locally hardened by travertine, or locally impregnated with asphalt, forming brea. The asphaltum also impregnates the older formations near fracture zones or outcrops of the oil sands.

STRUCTURE.

The McKittrick field offers the most difficult structural problems of all the California districts so far examined. Fortunately, the writers have had the advantage of studying the logs of practically every well ever put down in the field, and without these even the very incomplete underground map (Pl. II) accompanying this report would have been an impossibility. As it is, many problems remain quite unsolved and many of the conclusions drawn are still open for discussion.

Broadly speaking, the productive McKittrick field lies on the flanks of three more or less local and highly complex folds subsidiary to the great northeast dipping monocline of the Temblor Range. Thrust faulting and overturning have so complicated the folding as to place the older beds above the younger more commonly than in their normal relation.

From the northern end of the field, in the vicinity of the Frazer Spring fault, to the faulted zone which passes northeast and southwest across the NW. ¼ sec. 19, T. 30 S., R. 22 E., the Monterey and Santa Margarita (?) formations are thrust practically horizontally

northeastward for more than a mile at the point of maximum displacement over the McKittrick beds, which originally formed the northeast flank of a normal anticline. The fault crossing northwest and southeast across sec. 1, T. 30 S., R. 21 E., marks the eastern limit of this thrust as at present recorded in the beds. Figure 2 (p. 97) illustrates in a general way the conditions as they are believed to exist in the north end of the field. A crumpling and folding of the shale, in which portions of the overlying beds were infolded with the latter, accompanied the thrusting. Erosion has removed the greater part of the overlying McKittrick from the overthrust shale area, but infolded remnants of the latter beds are still to be found throughout the field. As a result of the thrust faulting the wells in the northern portion of the field usually start down in the Santa Margarita (?) formation, pass across the fault, and into the younger McKittrick oil-bearing formation.

The conditions believed to exist at the southeast end of the field are shown in Plate V. Two anticlines, the Shamrock and the Dabney, are involved in the structure here. Both are overturned, but the Dabney is normal in the northwestern part of sec. 28, T. 30, R. 22. With the exception of one or two near the western edge of sec. 19, T. 30 S., R. 22 E., the productive wells penetrate sands on the flanks of the Dabney anticline. In the eastern part of sec. 19 and the western part of sec. 20 the productive wells penetrate the normal southwestern flank, on which is a local flexure or dome (see contour map, Pl. II), while in the southeastern part of sec. 20 and the northeastern part of sec. 29 the wells penetrate the overturned flank.

The Dabney anticline is alternately normal and overturned from immediately south of McKittrick to the region of the Belgian (Temblor-McKittrick) wells, in the southeastern part of sec. 34, T. 30 S., R. 22 E. The wells in this last-mentioned locality penetrate the oil zone of the McKittrick formation on the flanks of the Dabney anticline, which is here normal.

The structure of the McKittrick Valley is, broadly speaking, synclinal, local folds of varying degrees of magnitude affecting the trough. The hills on the northeastern side of the valley are traversed by two and possibly locally by three anticlines, with domed tops and steep-dipping and sometimes faulted flanks. Wells put down on these hills strike the oil-bearing zone at depths less than the wells put down in the McKittrick Valley.

ZONE B—OIL SANDS.

The productive sands of the McKittrick district are found at the base of the McKittrick formation, unconformably overlying the diatomaceous Santa Margarita (?) and Monterey formations. The productive zone (zone B), the one shown by contour on the map (Pl. II) consists of a series of coarse conglomerates and sand layers

interbedded with more or less important shale and shale partings, the whole series varying in thickness in the wells from 60 to nearly 500 feet, depending, in part at least, on the dip of the beds. In the northern part of the field zone B lies nearly horizontal and the thickness of the productive zone is usually between 100 and 240 feet; in the southern part the zone is overturned and stands nearly vertical (see Pl. V), and the wells sometimes penetrate as much as 500 feet of more or less productive sand. The sands consist largely of quartz grains, while the pebbles and cobbles are of granite, quartzite, flinty shale and hard sandstone. The sands along the southwestern edge of the productive territory are coarser than those at the south end of the field or on the flats in front of the hills, this fact accounting in a measure for the greater productivity of the wells along the foothills, which derive their oil from the bowlder sands. Shale is said to yield a little oil in some of the wells toward the south end of the field.

The sand and gravel of the productive zone (zone B) are usually poorly cemented, and generally accompany the oil from the wells in large quantities, especially when the well is new. Gas alone is sometimes powerful enough to force loose sand and cobbles from the wells, occasionally with extreme violence.

ZONE A—TAR AND GAS SANDS.

Tar and gas sands are intercalated in the shale which overlies the productive zone of the McKittrick field, as in other California oil districts studied by the senior author. This zone of minor impregnation varies greatly from well to well, clearly indicating the local character of the sand and shale strata comprising it and the restricted conditions causing the impregnation. The zone varies in thickness from 100 to 600 feet and the individual layers from a few inches to 60 feet or more. In composition the petroliferous layers are similar to the oil sands of zone B, being coarse sand generally containing pebbles and in some places cobbles. The upper sands of zone A generally carry gas or small quantities of tar, but the degree of impregnation increases downward, until near the base of the zone in many places the sands carry oil in commercial quantities. In the central portion of the field the lower part of zone A is practically continuous with the productive zone B. In the shallower wells near the northeastern corner of sec. 14, T. 30 S., R. 21 E., the gas pressure in beds at the base of zone A or on the top of zone B is extremely high.

BEDS ABOVE ZONE A.

Owing to the overturning or thrusting over of the shale it is not unusual to find the wells in the McKittrick field starting down in beds (usually diatomaceous middle Miocene) older than the oil sands pene-

trated at the bottom of the well. This is true particularly in the southern end of the field, where shale (usually more or less petroliferous) is penetrated all the way down to the oil sands. In the central and northern portions of the field the wells, after penetrating the shale for a distance, pass through the plane of horizontal faulting and enter the sands and clays of the McKittrick formation overlying the petroliferous zones. In a few rare instances, such as near the middle of the E. ½ sec. 19, T. 30 S., R. 22 E., and near the middle of the NW. ¼ sec. 13, T. 30 S., R. 21 E., the wells are believed to penetrate the overturned limb of the productive zone (zone B) before entering the tar and gas zone (zone A) which overlies zone B in its normal position. This case is illustrated by Plate V. Water sands sometimes occur just above zone A, especially in the wells on or near the edge of the McKittrick Valley.

BEDS BELOW ZONE B.

The strata below zone B, where it is lying in its normal position, consist almost entirely of brown shale containing scattering sandstone lenses. Where the beds are overturned the layers underlying zone B are usually coarser than the shale which normally occupies that position. Water occurs in many wells between the base of the productive sands and the shale.

WATER SANDS.

With few exceptions the wells in the McKittrick field encounter water-bearing strata at one point or another below the surface. It may be said in general that water is more abundant in the wells drilled in the McKittrick Valley or near its edge and in the small valleys, such as the one in the western part of secs. 12 and 13, T. 30 S., R. 21 E., than in the wells drilled in the hills. This statement is true more particularly as regards the waters (surface waters) in the strata above the petroliferous zones, although it is also usually applicable to the strata below the oil sands. Only in rare instances is water found within the petroliferous zones.

The first water is encountered a few feet to over 1,000 feet above zone A (200 feet to 1,300 feet above zone B) and 25 to 600 feet, and possibly more, below the surface. All of this water is highly mineralized and useless for most purposes.

Warm sulphur water is known to underlie the oil sands of zone B over at least a part of the McKittrick field, and is believed by most of the operators to underlie them in many wells that have not yet gone below the base of the productive measures. For this reason it is customary to stop drilling before reaching the base of zone B. Some wells have gone through zone B and into the brown shale below without encountering the sulphur water, which proves that the water is, in part at least, local in distribution.

The relation of this sulphur water to the production of oil is most important, for within the last four or five years the water has come to replace the oil in the product of the wells to such an extent as to jeopardize profitable operation in certain portions of the field.

That the water was not in the oil zone when drilling began is clearly attested by the records of the early wells put down in various parts of the field. It is therefore obvious that the water has been introduced into the oil sands artificially. Opinions differ as to how the water comes in and what well or wells are responsible for the menacing conditions. Some of the operators have made exhaustive studies in an effort to discover the source of the water, so that the trouble could be remedied, but so far little headway has been made along these commendable lines. It is the belief of many, and this belief is shared by the writers, that the water comes from wells that have drilled too deep and penetrated the sulphur-water sand, and that the water from this sand being under a strong artesian pressure, has passed up through the casing and out through the perforations of the offending well or wells, or else has broken through the weakened strata adjacent to the casing and reached the overlying oil sands, which it invades, with a consequent partial or complete dispersion of the oil contents.

In some wells the increase in the percentage of water in the total product has been gradual, in others it has been very rapid, and in many more the percentage often fluctuates. No well-founded explanation has so far been advanced to account for this variation in behavior in wells apparently affected by practically similar conditions.

PRODUCT.

The oil from the wells of the McKittrick field is black to brownish in color and varies in gravity from 12.5° to 24° Baumé, the last being unusually light and, so far as known, produced only by one well. At the north end of the field it ranges between 12.5° and 21° Baumé, average 15° or 16°; the variation in the central part of the field is between 12° and 24° Baumé, average 15° to 17°; the gravity of the oil in the southern end of the field is uniform and of about 18° Baumé gravity, while the gravity of oil from wells in the valley and in the hills north of the McKittrick Valley runs from 12° to 14°, or possibly a little lighter. Gas usually accompanies the oil.

PRODUCTION.

The production of the individual wells in the McKittrick field varies from 2 to 1,500 barrels of oil per day, the last being the initial production of early and unusually prolific wells. At present the production of the individual wells toward the north end of the field runs from 50 to 300 barrels per day, with an average of something over 100

barrels; that of the central portion from 20 to 1,000 barrels, with a possible average of 125 barrels; and that of the wells of the K. T. & O.-Dabney area at the southeast end of the field, 2 to 60 barrels. The wells in the Belgian-Monarch area and in the foothills north of McKittrick produce or have produced individually from 10 to over 100 barrels per day, but only two or three of them are now being operated.

METHODS.

Except a very few that still flow, all the wells in the McKittrick field are pumped. The water and oil are separated in earthen reservoirs, the water being allowed to escape through pipes tapping the reservoirs near the bottom, while the oil is conveyed from the top.

TRANSPORTATION.

Practically all of the oil is now shipped from McKittrick in tank cars over the Southern Pacific Railroad. Two 8-inch pipe lines connecting the McKittrick district with tide water are now in course of construction. One, being built by the Producers Transportation Company (controlled by the Union Oil Company), will reach the ocean at Port Harford by way of Antelope Valley, Polonio Pass, Santa Margarita, and San Luis Obispo. The other, being built by the Associated Oil Company, goes by way of the San Joaquin Valley and reaches San Francisco Bay.

LOCAL AREAS OF THE McKITTRICK FIELD.

EAST PUENTE—SAN FRANCISCO—McKITTRICK—C. J. AREA.

Location.—The area denoted by the heading above consists of the southeastern part of sec. 3, the southwestern part of sec. 2, the northeastern part of sec. 10, all of sec. 11, the southwestern part of sec. 12, the northeastern part of sec. 14, and the northwestern corner of sec. 13, T. 30 S., R. 21 E., and includes among others the following leases: Wier (Associated), Result, Graham (secs. 10 and 11), Jackson (secs. 2 and 11), Foltz (K. T. & O.), Madison, C. J. (secs. 11 and 13), East Puente, Giant (Associated) (sec. 11), Reward (sec. 11), Buena Vista (K. T. & O.), and San Francisco-McKittrick.

Structure.—The wells in this area penetrate McKittrick beds on the northeastern flank of the McKittrick anticline, over which has been faulted the older diatomaceous shales of middle Miocene age. (See fig. 2, p. 97.) This flank becomes more or less folded in the region of sec. 11, and is finally truncated by the Frazer Spring fault, visible at the surface as it cuts across from the southwest to the northeast corner of the NW. ¼ sec. 2.

How far this fault extends southwestward from its southwesternmost appearance on the surface at the Frazer Spring-McKittrick road near the middle of the west line of sec. 2, it is not possible to state, but

its effect on the oil-bearing strata is exerted at least as far as the southern part of sec. 3. Near its northeastern end the downthrow of the fault is on the northwest side, while farther southwest it seems to be on the southeast side. The displacement, judging by an examination of the logs of those wells which have been drilled near the fault, is not of such maginitude as to move the oil sands either up or down for any great distance. In fact it is the belief of the writers that zone B underlies the Frazer Spring region, probably between 800 and 2,000 feet below the surface, but it is evident, from the results obtained by prospect holes, that zone B has lost nearly all of its petroleum contents in the immediate vicinity of the fault.

Zone B.—The productive oil zone, zone B, is encountered in nearly all the wells of this area drilled northeast of the line of truncation of the McKittrick anticline and southeast of the Frazer Spring fault. Its total thickness varies from 50 feet to more than 240 feet, and it consists usually of two or more individual sands separated by partings of blue clay. The average thickness of the zone for the area is about 125 feet. The sand is coarse, usually carries pebbles, and consists largely of quartz and feldspar grains. Beds carrying cobbles 1 foot or more in diameter occur in the zone, especially near its top. The pebbles and cobbles consist largely of granite with some gray sandstone, blue chert or quartzite, and black flinty shale. The sand is more or less loose and flows out with the oil when the wells are first operated, but the coarser pebbles and cobbles soon collect around the casing and act as a strainer, reducing the amount of sand that escapes with the oil. Zone B becomes less and less productive toward the Frazer Spring fault, and is said to carry water in some parts of the region of the fault and southeast of it for at least one-half mile.

Zone A.—Tar and gas sands occur above zone B in nearly all the wells of the area, especially in those in the central part of sec. 11. Little uniformity in these petroliferous sands is noticeable from well to well except that in most of them several tar and oil sands immediately overlie zone B, or else are separated from it by only a 25 to 60 foot shale parting. The tar sands occur in some of the wells as much as 300 feet above the top of zone B, although most of them occur not more than 100 feet above it. The individual sand beds in zone A vary from a few inches to over 65 feet in thickness, and consist usually of coarse quartz sand. No water sands are known to occur in zone A in any of the wells in the area.

Beds above zone A.—The beds above zone A consist of brown and blue shale and blue clay in which sand and cobble layers are sparingly intercalated. In one well a little southeast of the center of the SE. ¼ sec. 11 gravel is reported 140 to 390 feet below the surface. In other wells gravel layers from 30 feet to 65 feet through are penetrated above zone A. The gravels encountered near the surface may be accounted

for as surface deposits, but it is hard tc account for the gravel layers intercalated in the shale, in view of the nonoccurrence of these beds on the surface in the near-by regions, except on the hypothesis of the thrusting of the brown shales of the Santa Margarita(?) formation over the normally superjacent McKittrick beds (zone B and associated sands and shale).

Beds below zone B.—But two wells have, to the writers' knowledge, been drilled far below zone B, and these have penetrated blue and brown shale with intercalated thin, hard sand layers. No indications of oil were encountered, although water and some gas were found in three or four of the sands.

Water sands.—Water sands occur in the shale overlying zone A in practically all the wells in the area under discussion. These sands are more or less local in character, and it is often impossible to trace any connection between those of adjacent wells. They occur usually at 300 to 900 feet above the top of zone A, or 500 to 1,300 feet above the top of zone B, and at depths below the surface of 65 to nearly 600 feet. The usual depth is between 120 and 300 feet. The water sands vary in thickness penetrated from 10 to 45 feet, and consist of coarse sands, sometimes indistinguishable from the sand which carries the oil. The water from these upper sands is more or less mineralized. In one well in the northern part of the area water occurs associated with the tar sands near the base of zone A.

As disclosed by the logs, none of the productive wells in this area have penetrated the water sand, which is believed to lie below the oil zone (zone B), and for that reason water has given little trouble in the area. In one of the deeper wells along the northwestern edge of the proved productive territory water is encountered in a sand believed to be associated with or to lie just below the sands of zone B. This well was abandoned because of the water encountered in the oil zone. One of the deeper wells still farther west struck water sand at various depths in shale considerably below what is believed to be zone B (here unproductive). The water is not known to have an artesian head sufficient in any well to bring it above the surface.

The water struck at depths of 25 to less than 200 feet in the wells occupying the little valley in the western part of secs. 12 and 13, T. 30 S., R. 21 E., is believed to be surface water confined in surface wash in a basin in general coincident in extent with the valley. This surface water is undoubtedly the source of the spring in the canyon just north of the road in the SW. ¼ sec. 12. The waters in Frazer Spring and in similarly located springs in the canyons northwest as far as the Temblor ranch, in sec. 36, T. 29 S., R. 20 E., may also have their source in basins containing porous superficial wash deposits, although their occurrence may be accounted for by the peculiar structural conditions surrounding them.

Product.—The oil produced in this area is black, and varies in gravity from 12.5° to 21° Baumé. The last quality is uncommon, and is reported in but one well in the northeast corner of the NE. ¼ sec. 14. The average for the area is probably between 15° and 16°. The oil from the base of zone B in the northwestern part of the area is the heaviest found, and is viscous enough to cause trouble in some of the wells. More or less gas accompanies the oil, and is saved and used for domestic and development purposes on most of the leases. Sand is produced with the oil, especially for a short time after the wells are first operated. Practically no water occurs with the oil in this area.

Production.—The individual wells produce 50 to 300 barrels of oil per day, the average being somewhat over 100 barrels. The production is best in the southeastern portion, becoming less and less toward the northwest. This fall in production is doubtless connected with the more complicated structural conditions and faulting toward Frazer Spring. Unusual amounts of gas are produced by some of the wells. San Francisco-McKittrick well No. 11, in particular, gave a spectacular exhibition when the oil sand was penetrated by the drill. This well is high up on the flanks of the McKittrick anticline, where it would be natural to expect strong gas pressure. As soon as the well was opened into the sand the gas blew out great quantities of loose sand, pebbles, and cobbles, wrecking the derrick and strewing the ground with débris for many feet around. One of the cobbles blown out of this well was over 1 foot in diameter and weighed 33 pounds.

The "blow out" continued intermittently from 9.30 p. m. to midnight, the longest period of activity being twenty-five minutes, the periods of quiescence being about fifteen minutes. Although a good oil producer, this well still yields large quantities of gas. C. J. well No. 6, near the one just mentioned, also produces large quantities of gas.

Methods.—Most of the wells in this area are pumped, although when first drilled they usually flow more or less oil. Even after operation for some time, they can be made to flow by agitation.

Typical logs.—A typical log in the northwestern end of the area is recorded by the driller as follows:

Log of well near middle of NW. ¼ sec. 11, T. 30 S., R. 21 E.

	Feet.
Soil	60
White shale	110
Clay	120
Sand	130
Brown shale, cavy	180
Hard brown shale, cavy	225
Brown salvy shale	250
Sulphur shale	260

	Feet.
Brown shale	325
Brown hard shale	425
Brown shale, very cavy	510
Brown mud and hard shells	535
Mud (caving)	545
Brown mud and shale	575
Hard shell and salt water	585
Mud and shells	670
Brown mud and shells	740
Hard shells	750
Mud and shells	800
Loose sand, shale, and mud	850
Brown mud and shells	870
Hard shell	880
Blue sand and mud	900
Blue shale and shell (oil and gas)	908
Blue mud, shale, sand, and gravel	930
Light brown shale and oil	950
Brown mud, gravel, and shale	970
Shells and shale (strong showing of gas)	990
Gravel mixed with brown mud and shale	1,000
Blue shale (cased and cemented)	1,013
Shale with oil	1,050
Blue shale	1,100
Brown shells and sand cubes and gravel	1,125
Shells and blue shale	1,145
Brown shale (oil sand at 1,150 feet)	1,150
Very coarse (coarsest) oil sand	1,180
Fine oil sand	1,185
Shale, sands, and shells	1,215
Mud and cobbles	1,225
Hard shells, some shale	1,230
Coarse oil sand and bowlders	1,240

A log typical of the wells drilled near the middle of the area is as follows:

Log of well near center of sec. 11, T. 30 S., R. 21 E.

	Feet.
Water sand	70–75
Shale	140
Hard shell and sulphur water	145
Brown shale	215
Blue shale, sticky	260
Shelly formation	280
Brown shale	360
Shells and gravel	390
Sand and water	400
Shell, very hard	404
Brown shale	452
Sand, gravel, and water	471
Brown sticky shale	475
Shale	705
Brown sticky shale	733
Brown sandy shale	740

	Feet.
Oil sand	741
Brown shale (show of oil)	765
Blue clay	775
Brown shale	801
Oil sand, coarse, gas and sand	808
Shale, brown, sandy	811
Sand and shale	815
Oil sand and gravel	830

The log of a typical well in the group near the corner of secs. 11, 12, 13, and 14 is given by the driller as follows:

Log of well near corner of secs. 11, 12, 13, and 14, T. 30 S., R. 21 E.

	Feet.
Wash	20
Gypsum (water at 35 feet)	35
Clay and shells (at 71 feet stratum of gravel carrying much water, hard to case)	71
Shale, shells, and gravel	111
Broken shale and gravel (then sand and gravel)	150
Sticky clay (holds pipe)	168
Gravel (very bad, gets above tools)	178
Shale and clay	225
Blue clay and shale	265
Shale, hard and brittle, clay and shale (casing fell 5 feet, stopping in sticky clay, shutting off water, drove it 2 feet)	304
Water shut off in clay, but came in again	327
Water shut off in good shape in clay and shale	340½
Landed 11⅝ inches casing in sticky clay and shale	379
Shale and fine sand, carrying quite a bit of oil	421
Sticky clay	441
Clay	541
Clay and small streak of sand, carries some oil	580
Barren oil sand	599
Stray oil sand, coarse sand, and cobbles	618
Tar sand, carries some oil, hardly enough to perforate	632
Sand growing richer and better	650
Strike shell	660
Hard shell and sand; then good pay sand, oil sand	680
Oil sand and cobbles	697
Oil sand, passed through the cobbles after having 15 feet of them	712
Very good sand, shows more oil	732
Cobbles, blew up 75 feet in hole (1 foot cobbles)	734
Oil sand	735
Cobbles	739
Cobbles, rich in oil	742
Sand, rich in oil	748
Rich sand	757
Sand, coarse, rich in oil	776
Very rich streak of sand—lively—pipe followed 10 feet	780
Passed 7 feet of cobbles and sand, very lively and rich, pipe followed	800
Cobbles and gravel, very rich and lively, casing loose	816
Oil sand, rich	827
Sand, heaved up 75 feet	837
Sand, still good, heaved up	843
Quit drilling, plugged	846

REWARD—DEL MONTE—STATE AREA.

Location.—The area denoted by the heading consists of all of sec. 13, T. 30 S., R. 21 E., except the northwest corner, sec. 18, and the northwestern part of sec. 19, T. 30 S., R. 22 E., and includes the following leases: Reward No. 1, Giant (Associated) (sec. 13), Kern River, Kern Trading and Oil (K. T. & O.) (sec. 13), Del Monte (Associated), Olig Crude, McKittrick, McKittrick Consolidated, Chandler, Wilson & Bandettini (C. W. & B.), Sans Souci, Del Monte (Associated) (sec. 19), Silver Bow, and State. It contains the best producers in the McKittrick field.

Structure.—The wells in this area penetrate the northeastern flank of the McKittrick anticline, which has a low dip at the edge of the McKittrick Valley, but becomes steeper toward the axis, and is faulted off near the axis, the fault locally limiting the productive territory on the southwest. The details of the structure are shown on the map (Pl. II) and in figure 2 (p. 97).

Zone B.—Under this heading will be described the principal oil-bearing zone. In some parts of the area, notably the southeastern, the zone of oil-bearing strata is over 600 feet thick, but it is only the lower one-third of this thicker zone that is believed to be the equivalent of what is called the "oil sand" or "rich oil sand" in other parts of the area. For this reason only the lower richer sands in the region of the thicker petroliferous series will be included in zone B as here described. The distance of the top of this zone above sea level is indicated by contours on the map (Pl. II). Little regularity in the thickness of zone B is shown by an examination of the logs, owing to the extreme local variation in the sedimentation, and in part also to difference in the personal factor introduced by the drillers.

In the northern part of sec. 13, zone B consists of one well-defined and persistent sand which in some of the wells contains a shale parting at one-fourth to one-third of its depth from the top. The total thickness of the productive sand varies from 25 to a little over 250 feet, the average being about 100 feet.

In the eastern part of sec. 13 and the western part of sec. 19, zone B ranges from 40 to 180 feet in thickness, the zone sometimes being divided by one or more partings of brown shale. In the wells in the north-central part of the NW. ¼ sec. 19, the shale parting between the top portion ("first sand") and lower portion ("second sand") is 80 feet thick and carries traces of oil. Dry white sand and sand shells are also associated with the oil sand in portions of the southeastern end of the area.

In the flat, which includes the southwestern part of sec. 18, zone B varies from 8 to 150 feet in thickness and in most places, especially in the thicker portions, contains a 35-foot blue clay and sand shell part-

ing near the top. The sands in the flat are finer grained than those in the wells to the southwest, and carry small pebbles.

The sands of zone B consist largely of material derived from granitic rocks, such as quartz and feldspar grains, and usually contain pebbles and often cobbles of granite, quartzite, and other metamorphic and plutonic rocks. Seashells (*Pecten eldridgei* Arnold) indicating that the oil sand is a part of the McKittrick formation and the same as that exposed in the hill just south of the Dabney water wells in the middle of the E. ½ sec. 29, T. 30 S., R. 22 E., are found in the wells in the northern part of sec. 13. The sand as a rule is quite incoherent, and when the gas pressure is strong flows out with the oil, often in considerable quantities.

Zone A.—Oil, tar, and gas sands of varying importance overlie the productive zone B in most of the wells of the area under discussion. In the region of the middle of the NW. ¼ sec. 13, some of these upper tar sands may be the overturned portion of the same beds that lower down in the same wells comprise the productive sands (zone B). Farther toward the southeast and out on the flat in sec. 18 the overlying tar sands are believed to represent a local coarsening of the McKittrick strata overlying the basal and most productive beds.

Near the center of the NW. ¼ sec. 13 the tar sands are encountered near the surface and range in thickness from 100 to nearly 200 feet; they are medium to coarse grained and carry heavy tar or indications of oil. About 60 feet above the top of zone B in this locality is another zone of tar sands about 100 feet thick in which bowlders are a prominent feature; gas under considerable pressure also occurs in this lower zone of tar sands.

In the north-central part of the N. ½ sec. 13 the strata above the productive zone B carry few indications of petroleum, although porous beds such as coarse sands and cobble layers are present.

Signs of petroleum and gas are encountered in the brown shale and in intercalated sand and pebbly layers above zone B in the wells in the central-southern part of the N. ½ sec. 13, and from there southeastward to the region about the northwest corner of sec. 19 the petroliferous character of zone A becomes more and more pronounced. In the region last mentioned zone A is practically continuous with zone B, carries commercial quantities of oil in some of its sands (these usually being perforated), and attains a thickness of 200 to 400 feet in the wells. It here consists of alternating sands, gravels, and shale, the two former largely predominating. One of the most common occurrences in the wells of this area and also in the area to the northwest is a coarse gravel or sand layer, at the top of zone B or base of zone A, carrying large quantities of gas under great pressure.

In the flat in sec. 18 zone A extends as much as 600 feet above zone B, and water sands often mark the top of zone A. In one well near the west line of the SW. ¼ sec. 18 a gas pocket was encountered 200 feet above the top of zone B, in which the pressure was great enough to blow 600 feet of water out of the hole and prevent drilling for several days.

Barren sand layers are intercalated with the shale and petroliferous sands and gravels in zone A, usually in its upper portion. It is hard to account for the absence of indications of hydrocarbons in these sands, especially as they are sometimes overlain and underlain by sands carrying appreciable quantities of oil or gas. A possible explanation is that these sands are parts of lenses which are completely isolated from the rest of the strata by practically impervious layers of clay.

Beds above zone A.—The beds above zone A consist largely of brown shale, more or less sandy, in which are intercalated occasional sand and cobble lenses, some of which carry water, especially on the flat.

Beds below zone B.—The beds below zone B are largely brown diatomaceous shale believed to be of Santa Margarita age. Water sands, possibly representing the very base of the McKittrick, often occur immediately at the base of the productive sand, with little parting between the two.

Water sands.—Beds of coarse material, and sand carrying mineralized or salt water, occur above the beds of zone A in some of the wells, especially those on the flat, although it must be admitted that even in this advantageous position for accumulation water is not found in all the wells, which shows the local character of the lenses carrying it.

Water under hydrostatic pressure occurs below the oil sand (zone B) in the western part of sec. 18. This water sand has been penetrated by several wells in the area, and in one notable instance, McKittrick well No. 5, has never been shut off. This well flows with a constant stream of over 70 miner's inches of warm sulphur water so charged with hydrogen sulphide gas that when once ignited the well will burn until put out by an unusual draft of air. It is the belief of most of the operators in the field that the water, which is gradually replacing the oil in many of the wells, comes from some of the wells which penetrate the bottom sand and have not had the water properly shut off.

Sand carrying salt water was encountered at about 1,600 feet in a well put down in the Santa Margarita (?) formation in the eastern part of the SE. ¼ sec. 13.

Product.—The wells in the area under discussion yield dark-brown to black oil varying in gravity from 12.6° to 18.2° Baumé. The

heaviest oil is produced by the wells on the flat, the lightest by one of the wells near the northwest end of the area. In a general way the wells at the extreme northwestern end run between 16° and 17° Baumé; those in the region of the central northern part of the N. ½ sec. 13 average 15° to 16°; those just south of the last-mentioned average 16° to 17°; those in the SE. ¼ sec. 13 run between 12.6° and 16°, and those in the NW. ¼ sec. 19 average about 15.5°. The oil comes from the wells at a temperature of about 88° to 90° F. Sand accompanies the oil in most of the wells, while more or less water is found in practically all of the wells after they have been producing for some time. The percentage of water varies from well to well, and from time to time in the same well, and ranges between a mere trace in the product to practically the total. A further discussion of the occurrence of water will be found on pages 114–115.

Gas occurs with the oil in zone B and zone A, and also in sands in zone A. A particularly persistent occurrence of the gas is noted at the top of zone B or the base of zone A in many of the wells. The gas from many of the wells is saved and used for domestic purposes and for development work throughout the field. The gas pressure in one of the wells in the NE. ¼ sec. 13 was estimated as 700 pounds per square inch.

Production.—The best producers in the area are in the northern part of the NE. ¼ sec. 13. One well recently drilled here averaged over 1,000 barrels a day for over forty-two days. Still another flowed with an average of 1,500 barrels per day for three months; still another with 500 barrels per day for six months; and most of them average 150 to 300 barrels when first drilled. Under normal conditions the individual wells in the northwestern part of the area under discussion produce 50 to 200 barrels per day; under present conditions of flooding the same wells produce 10 to 100 barrels of oil.

The production of the individual wells in the eastern part of sec. 13 and the northwestern part of sec. 19 ranges from 40 to 300 barrels per day, the wells in the deeper territory usually yielding the best results. Water is beginning to affect production in this area, but not as much as farther northwest.

The wells in the flat in sec. 18 produce on an average a little over 100 barrels per day. In the fall of 1908 little trouble was caused by water in this area, but by the fall of 1909 water was materially affecting the wells, as in other parts of the field.

Methods.—All the wells in the area are pumped, except a few in which the gas pressure is strong enough to cause the oil to flow. A new type of pump, in which the rods are connected direct to a vertical cylinder over the well, has been invented by the superintendent, Mr. Ball, and used with excellent results in the Kern River

lease. The separation of the oil, water, and sand is accomplished in open earthen reservoirs.

Typical logs.—The following log is typical of the extreme northwestern end of the area, where it is believed that the oil sand may possibly be doubled back over itself in such a way as to appear in the well near the surface as well as at a depth:

Log of well near center of NW. ¼ sec. 13, T. 30 S., R. 21 E.

	Feet.
Sand, gypsum, and bowlders	50
Gray sand	60
Gypsum	65
Sandy clay	80
Dry oil sand	170
Gray sand	175
Dry oil sand	195
Blue clay	200
Dry oil sand	230
Brown shale	335
Brown shale and bowlders	485
Dry oil sand	500
Brown shale	515
Bowlders	520
Brown shale	550
Bowlders	570
Blue clay	580
Dry oil sand	595
Brown shale	665
Sand and gas	690
Oil sand	908

A characteristic log of the central part of the N. ½ sec. 13 is as follows:

Log of well near center of N. ½ sec. 13, T. 30 S., R. 21 E.

	Feet.
Surface (gypsum and shale)	20
Brown shale	300
Brown shale and oil sand, sticky and heavy	364
Oil sand	445
Oil sands and bowlders	460
Blue clay and oil sand	480
Blue clay	490
Oil sand	550
Oil sand and bowlders	580
Sticky blue clay	640
Clay and shale	680
Oil sand and shale	715
Oil sand	835
Brown shale	850

A typical log of the wells in the central southeastern part of the area is as follows:

Log of well near east line of SW. ¼ sec. 13, T. 30 S., R. 21 E.

	Feet.
Shale	175
Brown shale, shell, gas, and water	450
Shale	605
Shale, some water, sandstone	625
Oil sand	631
Sand, some oil	650
Rich oil sand	665
Sand	690
Sand, carrying some oil	740
Good oil sand	785
Good oil sand, coarse	790
Light sand, some oil	805
Shale and shell	825
Coarse, rich oil sand	830
Sand, little oil	845
Coarse sand, some oil	880
Rich oil sand	910
Oil sand, layers of slate	1,106

A typical log of the wells drilled in the southeastern portion of the area under discussion is as follows:

Log of well near center of NW. ¼ sec. 19, T. 30 S., R. 22 E.

	Feet.
Gypsum	15
Asphaltum	70
Decomposed brown shale containing some oil	80
Decomposed mixture of shale containing some water	120
Soft brown shale	530
Firmer brown shale	540
Oil sand	595
Shell with occasional streak of 1 to 2 feet good oil sand	635
Sand, heavier oil	715
Lively coarse oil sand and bowlders	725
Sticky brown shale	760
Very rich oil sand (stopped)	940

A characteristic log of the wells drilled in the flat in sec. 18 is given by the driller as follows:

Log of well in W. ½ sec. 18, T. 30 S., R. 22 E.

	Feet.
Surface	160
Cavy clay	210
Blue shale	225
Shell	228
Cavy clay	250
Shell	252
Blue clay	265
Sulphur sand	290
Brown shale	292
Sandy shale	294
Blue clay	310
Water sand	318

	Feet.
Blue clay	323
Shell	330
Shale	350
Shell	355
Blue clay	390
Sandy shale	450
Blue clay	485
Sandy shale	495
Blue clay	510
Hard shell	515
Blue clay	550
Stray sand with much oil	585
Shale	630
Blue clay	640
Clay, sand, and shale	650
Shell	652
Brown clay	665
Brown shale (full of shells; carries oil)	750
Blue clay and brown shale	765
Blue clay and sand (gas)	780
Blue clay and shale	805
Brown shale and sand	840
Stray oil sand	845
Asphaltum and blue shale	900
Blue clay	930
Asphalt sand	945
Blue clay and shells	953
Hard shell	956
Blue shale	976
Oil sand	1,042
White hard sand	1,046

SHAMROCK–K. T. & O.—DABNEY AREA.

LOCATION.

The area denoted by the heading above consists of the E. ½ sec. 19, the southwestern part of sec. 20, the northeastern part of sec. 29, T. 30 S., R. 22 E., and the northwestern part of sec. 28, and includes the following leases: Giant (sec. 19), Shamrock, Western Petroleum, Giant (sec. 20), Virginia, California Standard (sec. 20), K. T. & O. (sec. 20), Twenty, Providence (formerly and better known as the Dabney), Giant (sec. 28), Vancouver, and California Standard (sec. 28), including the old Spencer lease.

The complicated structure in this part of the field renders it desirable for purposes of description of the detailed geology of the wells to divide the area under discussion into two subareas. The first will include the Shamrock, Virginia, Western Petroleum, and Giant wells. The second includes the K. T. & O. and the Providence and wells southeast of the latter in sec. 28.

STRUCTURE.

Two overturned, compressed, and possibly faulted anticlines, on the flanks of one of which is a local flexure, are involved in the structure of this area. The overturning has been toward the northeast, and the planes of the respective axes slope toward the southwest, and consequently the axes of the folds appear at the surface northeast of the points where the same axes are penetrated by the wells. The axis of the anticline, which is here called the Shamrock anticline, may be traced from a little north of the southeast corner of sec. 38 in a northwesterly direction to near the center of the NW. ¼ of the same section. It is impossible to determine the exact position of the axis in the distorted shales, but its approximate position may be calculated from the two parallel contacts between the shales of the Santa Margarita(?) and the sandstone of the McKittrick, which are believed to lie equidistant from the axis on either side. The axis through here is marked by tar springs. It passes westward from the center of the NW. ¼ sec. 28 between the sandstone hills on either side of the Dabney water wells, near the middle of the NE. ¼ sec. 29, then swings northwest and passes approximately through the northwest corner of sec. 29. The course of the anticline through the NW. ¼ sec. 29 is marked by a series of tar seepages in the shale. The trace of the Shamrock anticline through sec. 19 is sinuous; it enters the section at the southeast corner, passing northwestward to near the center of the SE. ¼, then swings north to a point near the center of the NE. ¼ sec. 19, where it again turns to a northwest trend, passing out of the section near the middle of the north line of the section. The shales of the Santa Margarita(?) are exposed along the axis of the anticline throughout its whole extent, as described, but the unconformably overlying McKittrick formation (oil sand) is usually exposed close by on the flanks.

The Dabney anticline starts in the shale area in the NW. ¼ sec. 28, passes westward into the northern part of the NE. ¼ sec. 29, swings to a northwest trend to the center of the SW. ¼ sec. 20, thence northward and northwestward across the southwestern corner of the NW. ¼ sec. 20, and finally into the NE. ¼ sec. 19. The trace of this anticline also is marked by tar springs and brea deposits. It is overturned on the surface only northwest of the eastern part of the SW. ¼ sec. 20, although the well logs indicate that the steep southeast dips exposed at the surface in the lowest McKittrick layers (oil sands) in the southern part of sec. 20 bow under to a steep southwest dip not far below the surface.

The Shamrock and Western Petroleum well logs disclose an anticlinal flexure on the southwest flank of the Dabney anticline. It is in the apex of this minor anticline that Shamrock No. 3 is drilled,

and it is its position relative to this anticline that is believed to account for the unusual amount of gas and oil produced by this well.

The syncline between the Shamrock and Dabney anticlines is closely folded in the southeastern part of its course, but widens a little in the SW. ¼ sec. 20. It contains infolded sands of the McKittrick, which form the resistant east-west ridge through the center of the NE. ¼ sec. 29. In the eastern part of sec. 19 and the western part of sec. 20 the same sands are less sharply squeezed, though overturned.

SHAMROCK-VIRGINIA SUBAREA.

Zone B.—Zone B in the subarea denoted above dips southwestward, for the most part occupying the flexed southwestern flank of the Dabney anticline. The overturning of the Shamrock anticline has folded zone B back over itself (see Pl. V) beginning at a point a short distance southwest of Giant No. 51 and Shamrock No. 8, so that all wells between the line of folding and the outcrop of the oil sand (which occurs on the hill in the northern part of the NE. ¼ sec. 19) pass through zone B twice. Zone B varies in the thickness penetrated by the wells from 100 to 230 feet, being thicker in the shallower wells, where the dip of the strata is believed to be steeper than toward the bottom of the syncline, where the dip is less. The sand is coarse and consists largely of quartz grains; it becomes pebbly and finally full of large cobbles toward its base, although cobbles occur at various points throughout the zone in certain of the wells. In some of the wells one or more shale partings occur in the zone, but these are usually of minor importance. There is great variation from well to well as regards what portions of the zone are most productive. In one well the upper portion may be the richest, in an adjacent well the lower. The latter case appears to be the more common. Water occurs below zone B, especially in the syncline between the Shamrock and Dabney anticlines, but is separated from the oil sands by enough clay to permit the landing of the casing after zone B has been passed through.

Zone A.—Zone A includes those beds above the more important productive sands (zone B) which carry more or less gas, oil, or tar. As so defined, it would include the same beds that are described under zone B in those wells where zone B has been folded back over itself by the overturned Shamrock anticline. The overturned part of zone B varies in thickness in the wells from about 150 to 270 feet, and is more or less productive in those wells striking it at 300 feet or more from the surface. In wells passing through zone B within 300 feet of the surface it is usually reported in the logs as "dry surface formation," and consists of coarse sand, pebbles, and cobbles. Isolated lenses of sand carrying traces of oil and gas occur in the shale of the Santa Margarita(?) formation 200 to 500 feet strati-

graphically below zone B (but where overturned, occurring above it in the wells). Oil and tar sands occur in the McKittrick formation 50 to 400 feet above the top of zone B. A rather persistent layer, varying from 25 to 30 feet in thickness and sometimes carrying a parting near the middle, occurs at about 600 feet above zone B. This sand is said to carry light oil in places. Another lens or layer from 20 to 70 feet thick occurs in some of the wells about 400 feet above zone B. Most of the wells report traces of oil and gas or asphaltum throughout most of the finer grained formations from a few feet below the surface to the top of zone B; the hydrocarbons are too widely disseminated in this zone, however, to be of commercial importance. Just above zone B is a fine sand which is often described by the driller as "putty sand." Alternating hard and soft oil-bearing shale beds lie above the "putty sand" and are called "coffee shales" because of the resemblance of the broken-up material to coarse ground coffee. The "coffee shale" varies in thickness from 500 to over 1,000 feet as penetrated by the wells. Oil-bearing brown shale lies above the "coffee shale."

Water sand.—Water occurs in some of the wells above zone B, being struck at various depths from 140 to 600 feet below the surface. Sometimes it occurs above and sometimes below the brown oil-bearing shale of the McKittrick. It is highly mineralized, but so far as known is not under enough head to bring it to the surface. Water also occurs beneath zone B in those wells which have penetrated far below the oil horizon. Some of the wells, however, even in the syncline, have gone 100 feet below the base of zone B and not encountered water. This indicates that the water occurs in local lenses.

Product.—The highest grade of oil produced in the McKittrick field comes from the wells of this subarea. It is brownish to blackish and varies in gravity from 14° to 24.3° Baumé, the last very unusual. The average is between 18° and 21°.

The 14° gravity oil is said to come from zone B in a well in the southeastern part of the area, in which the oil from the shales above is of 20° Baumé gravity. Large quantities of gas and considerable sand are produced with the oil, especially in the best wells. The sand is more troublesome at first, becoming less and less so as the gas pressure diminishes and the finer material is removed, and the coarser material concentrates around the casing as a strainer for the oil. The temperature of the oil as it comes from the wells is about 82° F.

Production.—The individual daily production of the wells of this subarea varies from 20 to over 500 barrels. One well had an initial production said to have been over 1,500 barrels per day, and to have kept this up for nearly two years. The average of the better pro-

ducers is between 80 and 200 barrels per day. With the exception of Shamrock No. 3, which penetrates the top of the local anticlinal flexure on the southwestern flank of the Dabney anticline, all the best producers strike zone B at about 1,000 feet or deeper.

Methods.—The productive wells in this subarea vary in depth from about 850 to over 1,800 feet. With the exception of two or three flowing wells, the producers are pumped. The sand is removed from the oil by settling in long, slightly tilted troughs.

Typical logs.—A typical log of the northwestern end of the area, in which zone B is folded back over itself, is as follows:

Log of well in northern part of SE. ¼ sec. 19, T. 30 S., R. 22 E.

	Feet.
Surface formation	20
Blue clay	100
Brown shale	200
Shale and sand	215
Hard shell	218
Slaty rock and oil sand	248
Oil sand	280
Dry sand and shale	360
Brown shale	550
Oil sand	571
Hard shell	585
Oil sand	640
Brown shale and oil	698
Hard shell of brown shale	704
Brown shale with oil (formation getting hard)	1,045
Brown shale mixed with oil sand	1,140
Oil sand	1,155
Brown shale	1,165

A log of one of the deeper wells, in the southeastern part of the subarea, which starts down on the outcrop of the oil sand, where it is doubled back over itself, is as follows:

Log of well in the SW. ¼ SW. ¼ sec. 20, T. 30 S., R. 22 E.

	Feet.
Surface wash and brown shale	150
Rich oil-bearing brown shale	180
Gravel and bowlders	190
Rich oil-bearing brown shale (at this depth a little water was encountered)	525
Oil-bearing brown shale (alternate hard and soft strata, gradually less oil bearing)	1,005
Brown mud or exceedingly fine sand, very sticky, and called "putty sand"	1,245
Fine-grained oil sand	1,270
Gravel and bowlders	1,279
Coarse-grained oil sand	1,345
Bluish putty sand	1,350

K. T. & O.-DABNEY SUBAREA.

Zone B.—Zone B in this subarea consists of the sand and conglomeratic beds at the base of the McKittrick formation which immediately overlie the soft, oil-impregnated diatomaceous brown shale of the Santa Margarita(?). In the proved productive northwestern part of the subarea the Dabney anticline is slightly overturned, becoming more so as the anticline passes to the southwest through the brea deposits in front of the hills west of McKittrick. (See Pl. V.) The wells, therefore, to reach the oil zone, start downward in the brown shale of the Santa Margarita(?) and enter the base of the oil zone. One of the wells near the south line of the SE. ¼ sec. 20 passes through zone B into the younger beds of the McKittrick, and then enters again what is believed to be the same bed (zone B) where it turns outward to its normal position under the flats. Where zone B is penetrated by the productive wells it dips very steeply, and for that reason its real thickness is greatly exaggerated by the distances through which the wells have to go in penetrating it.

As recorded in the well logs zone B consists of an alternation of 10 to 40 foot oil sands and 3 to 20 foot beds of blue shale or hard barren sand. Where the overthrust has been greatest, as in the eastern part of the SW. ¼ sec. 20, the distance through which the wells penetrate the zone is from 60 to 200 feet. Farther southeast, in the K. T. & O. and Dabney region, the wells penetrate about 200 feet to over 500 feet of more or less productive measures. The sand is more or less incoherent, consists of medium to coarse quartz grains, and often carries pebbles and cobbles of considerable size. The shale associated with the sand is said to yield oil in some places.

Zone A.—The brown shale overlying the oil sand in the wells (but in its normal position below zone B) contains more or less oil in the joint cracks. In fact the trace of the anticline through the strata is usually marked by surface seepages of tar or heavy oil which has passed upward through the cracks in the broken-up portions of the shale.

Beds below zone B.—The wells after passing through zone B enter brown shale, which is believed to be that associated with and normally above the oil sand (zone B) in the McKittrick formation. The deepest well but one (see log, p. 135) sunk in this subarea penetrated this brown shale of the McKittrick for nearly 500 feet below zone B, and then passed into dry or asphalt sand, believed by the writers to be zone B in its normal position. (See fig. 2.) This zone of sand was a little over 200 feet thick and carried a little heavy oil at the bottom. Below this sand was broken shale again, this believed to be true brown shale of the Santa Margarita(?), the same as that appearing above the oil sand in the overturned areas. Water was encountered at about 300 feet below the base of zone B. A well

recently drilled by the Providence Oil Company in the knoll west of the main road leading from McKittrick southeast to the Midway district is said to have penetrated brown shale from the surface to a depth of over 3,000 feet. The shale here is standing practically vertical.

Water sands.—Water occurs in some of the wells above the oil sand and is believed to occur below it in practically all the wells, though for obvious reasons most of the wells are stopped before entering the water-bearing zone. In those wells which have penetrated the water sands below zone B ("bottom water"), 60 feet of water-bearing strata are reported. Efforts have been made to shut this water off, for it is the opinion of some of the operators that the water which is now becoming a menace to this part of the field is "bottom water" and comes from the wells in which the underlying water sands were penetrated. It is almost superfluous to state that unless this condition of flooding is checked the whole of zone B will eventually be rendered unproductive. At present the yield of the wells varies from 1 per cent to 95 per cent water, and in one or two instances water is said to have entirely replaced the oil in the wells. Water for development purposes is produced in shallow wells in the southern part of the NE. ¼ sec. 29.

Product.—The product of the wells in this subarea is a dark-colored oil of about 18° Baumé. Gas accompanies the oil and more or less water is also pumped with it. Most of the wells yield more or less sand, said to be more in proportion to their yield of oil than is produced in many of the wells to the northwest.

Production.—The wells in this subarea vary in production from 2 to 60 barrels of oil per day. No regularity in variation in production is noted, the yield apparently depending on local conditions of the strata and the manipulation of the well.

Methods.—The wells vary in depth from about 400 to 600 feet, although one well was drilled to a depth of nearly 1,500 feet without, however, discovering productive sands below those encountered between 200 and 400 feet. Another well drilled in the brown shale a short distance southwest of the productive belt attained a depth of over 3,000 feet without encountering productive oil sands. All the wells are pumped; the gas is saved in a limited number only.

Typical logs.—A typical log near the middle of the productive area is as follows:

Log of well in the southwestern part of the SE. ¼ sec. 20, T. 30 S., R. 22 E.

	Feet.
Brown shale	33
Hard shale	35
Brown shale	105
Oil sand	125
Brown shale	130

	Feet.
Oil sand	153½
Shale	155
Oil sand	164
Shale	167
Oil sand and shale	169
Oil sand	200
Shale	211
Oil sand	231
Hard sand and shale	245
Oil sand	286
Hard sand and shale	297
Oil sand	308
Hard oil sand	320
Hard sand with oil	365
Oil sand	370
Rich shale and oil sand	413
Oil sand and gravel	420
Shale full of oil	460
Rich sand and gas	470
Very hard shale	500
Rich fine sand and gravel	510
Dry sand	516
Shale very rich between streaks	536
Shale	594

A log of a well in this subarea which it is believed penetrates zone B twice is as follows:

Log of well near middle of south line of SE. ¼ sec. 20, T. 30 S., R. 22 E.

	Feet.
Sand	120
Sand	220
Oil sand	283
Rich oil sand	400
Brown shale and shell	770
Asphaltum	782
Brown clay	795
Blue clay	835
Brown shale	840
Asphaltum	880
Dry sand	885
Asphalt	892
Dry sand	895
Asphalt	910
Dry sand	975
Shale	1,020
Dry sand	1,025
Sand and gravel	1,085
Shale, hard	1,087
Shale, heavy oil	1,095
Clay	1,115
Dry sand	1,118
Blue clay	1,165
Shale and shell, clay, no oil	1,475
Water	1,475

BELGIAN—NINETEEN ONE—MONARCH AREA.

Location.—This area embraces the region of sec. 34, T. 30 S., R. 22 E., and includes territory drilled by the Belgian (now Temblor-McKittrick), Nineteen One, and Monarch oil companies.

Structure.—The wells in this area penetrate the basal McKittrick beds on the flanks of the plunging Belgian anticline a short distance southeast of the point where the McKittrick closes around the end of the anticline, covering the Santa Margarita shale, which is exposed along the axis of the anticline from near McKittrick to the southwestern corner of sec. 27, T. 30 S., R. 22 E. The anticline enters sec. 34 near its northwestern corner and, passing southeastward to near the middle of the east half of the section, bends abruptly south and continues its southerly course to the middle of the south line of the SE. ¼ sec. 34, where it again bends to a southeasterly trend and passes off the end of a row of hills under the flats to the southeast, where the structure is hidden. Faults are associated with the anticline especially near the axis on its northeastern flank. The dips on the southeast side are steep, ranging from overturned to normal 70°, while those on the southwest limb vary from 30° to 44°, always normal.

Oil sands.—Oil and heavy tar sands have been encountered in all of the wells so far drilled in this area, the depth below the surface varying from about 450 feet to 1,300 feet, depending on the distance from the anticline. The oil zone consists of alternating blue and brown shale and impregnated sands, the total thickness of the zone as penetrated in the wells ranging from 5 to 50 feet. The sands are coarse and consist largely of quartz grains in which are scattered granitic pebbles.

Product and production.—The product of the wells in this area is black and varies from tar to oil of 14° or 15° Baumé gravity. The wells produce 2 or 3 barrels to 100 barrels per day, those on the northeastern side of the anticline yielding the most and the best oil. The productive wells vary from about 1,000 to 1,100 feet in depth. A little oil and gas were found escaping from between the casing of Monarch No. 1 well in the SW. ¼ sec. 34 when it was visited by the writers in September, 1908, although this well has stood idle for several years. The oils from the Temblor-McKittrick (formerly the Belgian) wells, the only ones operated in this area in September, 1908, pipe their product to a loading rack on the Southern Pacific Railroad at a siding below McKittrick.

U. S.—SEA BREEZE—FEARLESS AREA.

Location.—This area embraces the region of secs. 6, 7, 8, 9, 16, and 17, T. 30 S., R. 22 E., and the eastern part of sec. 1, T. 30 S., R. 21 E. It includes the territory prospected by the McKittrick, U. S., Sea Breeze, Empire, and Fearless oil companies and lies in the foothills immediately north and northwest of McKittrick.

Geology and structure.—The geologic formations exposed in this area are the soft sandstones and clay shales of the McKittrick formation. These beds are affected by two main anticlines, the Gould anticline and a parallel one, which pass from northwest to southeast through the prospected territory. The dips in the strata on the flanks of these anticlines are for the most part over 30° or 40° as exposed at the surface, but near the axes the dips become less and some beds believed to be practically horizontal were noted directly on the axes. In a general way the anticlines are symmetrical, but in certain instances faulting has affected the beds near the axes in such a way as to produce much steeper dips on one flank than on the other. Only five or six prospect holes have so far been drilled in this area, and nearly all of them have obtained oil in commercial quantities.

Oil sands.—The logs of the wells drilled in this area indicate that the oil-bearing zone lies from about 275 to over 500 feet below the surface in the central part. The oil zone is usually between 300 and 400 feet thick, although "stray" or isolated gas and tar sands are often found above and below the major part of the zone. The individual sands vary from 5 to over 40 feet in thickness and four or more of them are usually found within the petroliferous zone. The sands are separated by partings of blue clay, shale, or hard sand shell, which show about the same variation in thickness as is shown by the oil sands. The sand consists of quartz grains, is usually quite coarse, and often carries granitic pebbles up to three-fourths of an inch or possibly more in diameter. It is incoherent and, as shown by the sumps of the old wells, accompanies the oil from the hole. Some fossil clam shells were reported in the oil sand from one of the wells in the northwestern part of the area.

Product and production.—But little information is available concerning the quality of the oil produced by the wells in this area. At the time of the writer's visit to the field in the fall of 1908 heavy oil was found in the sump of several of the wells, which had the appearance of having been abandoned for at least three or four years. The gravity of this sump oil is probably about 10° or 11° Baumé or possibly heavier. When the oil first comes from the well it is said to have a gravity of about 14° Baumé. The production of those wells which were tested was 15 to 25 barrels per day. A considerable amount of sand accompanies the oil.

OIL COMPANIES AND OIL WELLS IN McKITTRICK DISTRICT.

In the following list of companies and wells the locations refer to the Mount Diablo base and meridian. The elevations were taken by aneroid barometer, except those marked "A," furnished by the Associated Oil Company, and those marked "K," by the Kern Trading and Oil Company.

Oil companies and oil wells in the McKittrick district.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Adirondack		1	W. ½ sec. 2, T. 30 S., R. 21 E	1,210
Argonaut. (*See* Everett.)				
Associated	Del Monte	1	NE. ¼ sec. 13, T. 30 S., R. 21 E	
Do	do	2	do	1,232 (A)
Do	do	3	do	1,197 (A)
Do	do	4	do	1,258 (A)
Do	do	5	do	
Do	do	6	do	
Do	do	7	do	1,205 (A)
Do	do	8	do	1,240 (A)
Do	do	9	do	1,251 (A)
Do	do	10	do	1,267 (A)
Do	do	11	do	1,325 (A)
Do	do	12	do	1,202 (A)
Do	do	13	do	
Do	do	14	do	1,272 (A)
Do	do	15	do	1,247 (A)
Do	do	16	do	1,270 (A)
Do	do	17	do	1,263 (A)
Do	do	18	do	1,279 (A)
Do	do	19	do	1,291 (A)
Do	do	20	do	
Do	do	21	do	
Do	do	22	do	
Do	do	23	do	
Do	do	24	do	
Do	do	25	do	
Do	do	26	SE. ¼ sec. 13, T. 30 S., R. 21 E	
Do	do	27	NE. ¼ sec. 13, T. 30 S., R. 21 E	
Do	do	28	do	
Do	do	29	do	
Do	do	30	do	
Do	do	31	do	
Do	do	32	do	
Do	do	33	do	
Do	do	34	do	
Do	do	35	do	
Do	do	36	do	1,174 (A)
Do	do	37	do	1,167 (A)
Do	do	38	SW. ¼ sec. 18, T. 30 S., R. 22 E	
Do	do	39	do	
Do	do	42	NW. ¼ sec. 19, T. 30 S., R. 22 E	
Do	do	49	do	1,295 (A)
Do	do	50	do	
Do	do	52	do	1,302
Do	do	53	do	1,319
Do	do	58	do	
Do	do	59	do	
Do	do	60	do	
Do	do	61	do	1,302 (A)
Do	Giant	1	Sec. 20, T. 30 S., R. 22 E	1,300
Do	do	2	do	1,212
Do	do	3	do	1,385
Do	do	4	Sec. 13, T. 30 S., R. 21 E	1,190 (K)
Do	do	5	Sec. 20, T. 30 S., R. 22 E	1,290
Do	do	6	Sec. 13, T. 30 S., R. 21 E	1,212 (A)
Do	do	7	do	1,212
Do	do	8	do	1,254 (A)
Do	do	9	do	1,210 (A)
Do	do	10	do	1,229 (A)
Do	do	11	do	1,259
Do	do	12		
Do	do	13		
Do	do	14		
Do	do	15		
Do	do	16	Sec. 11, T. 30 S., R. 21 E	1,340 (A)
Do	do	17	do	1,297
Do	do	51	Sec. 19, T. 30 S., R. 22 E	1,414 (A)
Do	do	18	Sec. 11, T. 30 S., R. 21 E	1,293
Do	do	19	do	1,315
Do	do	20	do	1,400
Do	do	21	do	1,420
Do	do	1	NE. ¼ sec. 19, T. 30 S., R. 22 E	1,150
Do	Goodyear	2	SW. ¼ sec. 30, T. 30 S., R. 21 E	1,380
Do	Nineteen hundred and one.	1	SE. ¼ sec. 34, T. 30 S., R. 22 E	1,530
Do		2	do	1,350
Do	Shamrock	1	SE. ¼ sec. 12, T. 30 S., R. 22 E	1,329
Do		2	do	1,370 (A)
Do		3	do	1,377 (A)

Oil companies and oil wells in the McKittrick district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Associated		4	SE. ¼ sec. 12, T. 30 S., R. 22 E.	
Do.		5	do.	1,432 (A)
Do.	Shamrock	6	do.	1,444 (A)
Do.	do.	7	do.	1,376 (A)
Do.	do.	8	do.	1,464 (A)
Do.	do.	9		
Do.	do.	10		
Do.	California Standard.	1	SW. ¼ sec. 20, T. 30 S., R. 22 E.	1,271
Do.	do.	2	do.	1,276
Do.	do.	3	do.	1,275
Do.	do.	4	do.	1,270
Do.	do.	5	do.	1,275
Do.	do.	6	do.	1,268 (K)
Do.	do.	7	do.	1,264 (K)
Do.	Western petroleum.	1	NW. ¼ sec. 20, T. 30 S., R. 22 E.	1,250
Do.	do.	2	do.	1,280
Do.	do.	3	do.	1,300
Do.	Wier	1	SE. ¼ sec. 3, T. 30 S., R. 21 E.	1,315
Ball & Williams		1	NE. ¼ sec. 2, T. 30 S., R. 21 E.	
Belgian. (*See* Temblor-McKittrick.)				
Belmont. (*See* East Puente.)				
Benedict. (*See* Madison; Merrill.)				
Bowles	Giant	1	NW. ¼ sec. 28, T. 30 S., R. 22 E.	
Do.	California Standard.	1	do.	1,268 (K)
Do.	do.	2	do.	1,264 (K)
Do.	Vancouver	1	do.	*a* 1,250
Do.	do.	2	do.	*a* 1,250
Do.	Giant	1	NE. ¼ sec. 28, T. 30 S., R. 22 E.	
Do.	Spencer	1	SW. ¼ sec. 28, T. 30 S., R. 22 E.	1,200
Do.	do.	2	do.	1,190
Bowles & McNear		1	SW. ¼ sec. 2, T. 30 S., R. 21 E.	
Do.	Result	1	SE. ¼ sec. 3, T. 30 S., R. 24 E.	1,307
Buena Vista. (*See* K. T. & O.)				
California Standard. (*See* Associated; Bowles.)				
Carmelita. (*See* K. T. & O.)				
Carolina	Everett	1	NE. ¼ sec. 10, T. 30 S., R. 21 E.	1,430
Do.		1	do.	
C. J.	Keller & Berry	1	NW. ¼ sec. 11, T. 30 S., R. 21 E.	1,340
Do.	do.	2	do.	1,365
Do.	do.	3	do.	1,415
Do.	do.	4	do.	1,440
Do.	do.	5	do.	1,415
Do.	do.	1	Secs. 11, 12, 13, 14, T. 30 S., R. 21 E.	1,283
Do.	do.	2	do.	1,278
Do.	do.	3	do.	1,275
Do.		4	do.	1,275
Do.		5	do.	1,265
Do.		6	do.	1,290
Do.		7	do.	1,280
Do.		8	do.	1,285
Do.		9	do.	1,300
Do.		10	do.	1,258
Commonwealth		1	SE. ¼ sec. 29, T. 30 S., R. 22 E.	1,300
Cousins. (*See* I. O. P. A.)				
C. W. & B.		1	SW. ¼ sec. 18, T. 30 S., R. 22 E.	1,209 (A)
Do.		2	do.	1,191 (A)
Do.		3	do.	1,193 (A)
Do.		4	do.	1,179 (A)
Do.		5	do.	1,186 (A)
Dabney. (*See* Providence.)				
East Puente	Belmont	1	SE. ¼ sec. 11, T. 30 S., R. 21 E.	1,437
Do.	Jerome	2	do.	1,433 (A)
Do.	Belmont	3	do.	1,438
Do.	do.	4	do.	1,430
Do.		5	do.	
Do.		6	do.	
Eclipse, formerly X-Ray. (*See* Jackson No. 1.)				
Empire. (*See* Wible, S. P.)				
Everett	Argonaut	1	SE. ¼ sec. 2, T. 30 S., R. 21 E.	1,300
Do.	Graham	1	NE. ¼ sec. 10, T. 30 S., R. 21 E.	1,360
Do.	do.	2	NW. ¼ sec. 11, T. 30 S., R. 21 E.	1,250
Do.	Venango	1	do.	1,280

a Approximate.

Oil companies and oil wells in the McKittrick district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Fearless		1	SW. ¼ sec. 16, T. 30 S., R. 22 E.	1,040
Do.		2	do.	1,070
Giant. (*See* Associated.)				
Goodyear. (*See* Associated.)				
Graham. (*See* Everett.)				
Green		1	SE. ¼ sec. 12, T. 30 S., R. 21 E.	1,077 (A)
Independent Oil Producers Agency.	Cousins	1	SW ¼ sec. 18, T. 30 S., R. 22 E.	1,207
Do.	do.	2	do.	1,196
Do.	do.	3	do.	1,191
Do.	do.	4	do.	1,185
Do.	do.	5	do.	1,182
Do.	do.	6	do.	1,165
Do.	do.	7	SE. ¼ sec. 12, T. 30 S., R. 21 E.	1,092
Do.		1	SW. ¼ sec. 18, T. 30 S., R. 22 E.	
Do.	Sans Souci	1	SE. ¼ sec. 18, T. 30 S., R. 22 E.	1,111
Jackson "No. 1"		1	NE. ¼ sec. 11, T. 30 S., R. 21 E.	1,260
Do.	Eclipse	1	do.	1,400
Do.		2	do.	1,275
Jackson "No. 2"		2	SW. ¼ sec. 2, T. 30 S., R. 21 E.	1,250
Jerome. (*See* East Puente.)				
Jewett	Kern River	1	NE. ¼ sec. 13, T. 30 S., R. 21 E.	1,205 (A)
Do.	do	2	do.	1,195
Do.	do	3	do.	1,175
Do.	do	4	do.	1,135
Do.	do	5	do.	1,225
Do.	do	7	do.	1,188
Do.	do	8	do.	1,225 (A)
Do.	do	9	do.	1,192 (A)
Do.	do	10	do.	1,202 (A)
Do.	do	11	do.	1,195 (A)
Do.	do	12	do.	1,181 (A)
Do.	do	13	do.	1,216 (A)
Do.	do	14	do.	
Do.	do	15	do.	
Kern River		A (6)	NE. ¼ sec. 13, T. 30 S., R. 21 E.	1,195
Do.		B	do.	
Do.		C	do.	
Do.		D	do.	
Kimble. (*See* Miller and Lux.)				
Kimble		2	do.	1,200
Klondike	Jewel	1	NE. ¼ sec. 2, T. 30 S., R. 21 E.	1,315
Do.	do.	2	do.	995
Do.	Jap	1	do.	1,120
Do.	Little Standard	1	SE. ¼ sec. 2, T. 30 S., R. 21 E.	1,160
Do.	do.	2	do.	1,340
K. T. & O		1	Sec. 1, T. 30 S., R. 21 E.	910
Do.		1	SE. ¼ sec. 20, T. 30 S., R. 22 E.	1,200
Do.		2	do.	
Do.		3	do.	1,233 (A)
Do.		4	do.	
Do.		5	do.	1,256 (A)
Do.		6	do.	1,267 (A)
Do.		7	do.	1,267 (A)
Do.		8	do.	1,273 (A)
Do.		9	do.	1,270 (K)
Do.		10	do.	1,269 (A)
Do.		11	do.	1,231 (K)
Do.		12	do.	1,247 (K)
Do.		13	do.	1,285 (K)
Do.		14		
Do.	Carmelita	1	NE. ¼ sec. 33, T. 30 S., R. 22 E.	1,400
Do.		15	NW. ¼ sec. 13, T. 30 S., R. 21 E.	1,217 (A)
Do.		16	do.	1,224 (K)
Do.		17	do.	1,242 (K)
Do.		18	do.	1,267 (K)
Do.		19	do.	1,287 (A)
Do.		20	do.	1,226 (A)
Do.		21	do.	1,243 (A)
Do.		22	do.	1,252 (A)
Do.		23	do.	1,273 (A)
Do.		24	do.	1,302 (K)
Do.		25	do.	1,305 (K)
Do.		26		
Do.	Buena Vista	101	SW. ¼ sec. 12, T. 30 S., R. 21 E.	1,268
Do.		102	do.	1,270
Do.		103	do.	1,248
Do.		104	do.	1,260
Do.		126	do.	

Oil companies and oil wells in the McKittrick district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
K. T. & O.	Foltz	1	SW. ¼ sec. 11, T. 30 S., R. 21 E.	1,433
Do.		2	do	1,438
Little Standard. (*See* K. T. & O.)				
McKittrick-Consolidated		1	N. ½ sec. 18, T. 30 S., R. 22 E.	1,100
Do.		2	do	1,100
Madison	Benedict	1	SW. ¼ sec. 11, T. 30 S., R. 21 E.	1,510
Do.	do	2	do	1,550
Do.		3	do	
McKittrick Extension		1	NE. ¼ sec. 18, T. 30 S., R. 22 E.	
McKittrick Oil Co.		1	NE. ¼ sec. 12, T. 30 S., R. 21 E.	1,100
Do.		2	NW. ¼ sec. 18, T. 30 S., R. 22 E.	1,115
Do.		3	do	1,115
Do.		4	Sec. 1, T. 30 S., R. 21 E.	910
Do.		5	NW. ¼ sec. 18, T. 30 S., R. 22 E.	1,110
Do.		6	do	1,115
Do.		7	do	1,115
Do.		8	NE. ¼ sec. 12, T. 30 S., R. 21 E.	980
Merrill	Benedict	1a	SW. ¼ sec. 11, T. 30 S., R. 21 E.	
Miller and Lux	Kimball	1	SE. ¼ sec. 3, T. 30 S., R. 21 E.	1,220
Do.	do	2	do	1,200
Monarch		1	SW. ¼ sec. 34, T. 30 S., R. 22 E.	1,410
Do.		2	do	1,400
Nacirema		1	NE. ¼ sec. 6, T. 30 S., R. 22 E.	
Nanticoke		1	SE. ¼ sec. 27, T. 30 S., R. 22 E.	1,200
Nineteen hundred and one. (*See* Associated.)				
Olig Crude		1	SE ¼ sec. 13, T. 30 S., R. 21 E.	1,315 (A)
Do.		2	do	1,327 (A)
Do.		3	do	
Do.		4	do	
Do.		5	do	
Do.		6	do	1,384
Our Own		1	NE. ¼ sec. 24, T. 30 S., R. 21 E.	1,700
Providence	Dabney	1	NE. ¼ sec. 29, T. 30 S., R. 22 E.	1,237
Do.	do	2	do	1,231
Do.	do	3	do	1,203 (K)
Do.	do	4	do	1,235
Do.	do	5	do	1,230
Do.	do	6	do	1,244
Do.	do	7	do	1,240
Do.	do	8	do	1,219 (K)
Do.	do	9	do	1,229
Do.	do	10	do	1,236
Do.	do	11	do	1,257
Do.	do	12	do	1,231 (K)
Do.	do	13	do	1,268
Do.	do	14	do	1,238 (K)
Do.	do	15	do	1,238
Do.	do	16	do	1,242
Do.	do	17	do	1,288
Do.	do	18	do	
Do.	do	19	do	
Do.	do	20	do	
Research		1	NE. ¼ sec. 2, T. 30 S., R. 21 E.	
Result. (*See* Bowles & McNear.)				
Reward		1	NW. ¼ sec. 13, T. 30 S., R. 21 E.	1,220 (K)
Do.		2	do	1,242 (K)
Do.		3	do	1,236 (A)
Do.		4	do	1,215 (K)
Do.		5	do	1,250 (K)
Do.		6	do	1,275 (K)
Do.		7	SE. ¼ sec. 11, T. 30 S., R. 21 E.	1,300
Do.		8	do	1,280
Do.		9	do	1,287
Do.		10	do	1,268
Do.		11		1,205 (K)
Do.		12	SE. ¼ sec. 11, T. 30 S., R. 21 E.	1,280
Do.		13		
Do.		14	SE. ¼ sec. 11, T. 30 S., R. 21 E.	1,260
Do.		15	do	1,275
Do.		16	do	
Do.		16	SW. ¼ sec. 12, T. 30 S., R. 21 E.	
Do.		18	do	
Do.		21	do	
Do.		17	NW. ¼ sec. 13, T. 30 S., R. 21 E.	1,275
Do.		18		
Do.		19	do	
Do.		20	do	

Oil companies and oil wells in the McKittrick district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Reward		a	Sec. 11, T. 30 S., R. 21 E	1,300
Do		b	....do	1,300
Do		c	....do	1,310
San Francisco-McKittrick		1		
Do		2		
Do		3	NE. ¼ sec. 14, T. 30 S., R. 21 E	1,288
Do		4	....do	1,287 (A)
Do		5	....do	1,276 (A)
Do		6	....do	1,279 (A)
Do		7	....do	1,285 (A)
Do		8	....do	1,286
Do		9	....do	1,307
Do		10	....do	1,335
Do		11	....do	1,370
Do		12	....do	
Do		13	....do	
Do		14	....do	
Do		15	....do	
Do		16	....do	
Sans Souci. (*See* I. O. P. A.)				
Sea Breeze		1	SW. ¼ sec. 6, T. 30 S., R. 22 E	920
Selkirk		1	SE. ¼ sec. 2, T. 30 S., R. 21 E	1,310
Shale Basin		1	NW. ¼ sec. 29, T. 30 S., R. 22 E	1,195
Do		2	....do	
Do		3		
Shamrock. (*See* Associated.)				
Silver Bow		1	NW. ¼ sec. 19, T. 30 S., R. 22 E	1,207 (A)
Do		2	....do	1,290
Do		3	....do	1,298 (A)
Do		4	....do	1,259 (A)
Do		5	....do	1,327 (A)
Do		6		
Do		7		
State		1	NW. ¼ sec. 19, T. 30 S., R. 22 E	1,296
Do		2	....do	1,299
Do		3	....do	1,287
Do		4	....do	1,298
Temblor-McKittrick	Belgian	1	NE. ¼ sec. 34, T. 30 S., R. 22 E	1,360
Do	....do	2	....do	1,415
Do	....do	3	....do	1,360
Twenty Oil		1	SE. ¼ sec. 20, T. 30 S., R. 22 E	1,195 (K)
Do		2	....do	1,201 (K)
U. S. Oil		1	NW. ¼ sec. 6, T. 30 S., R. 22 E	850
Do		2	....do	790
Do		3	SE. ¼ sec. 6, T. 30 S., R. 22 E	840
Vancouver. (*See* Bowles.)				
Venango. (*See* Everett.)				
Virginia		1	SW. ¼ sec. 20, T. 30 S., R. 22 E	1,390
Do		2	....do	1,410
Do		3	....do	1,350
Western Petroleum. (*See* Associated.)				
Wible, S. P	Empire	1	SW. ¼ sec. 8, T. 30 S., R. 22 E	950
Wier. (*See* Associated.)				
X-Ray. (*See* Eclipse.)				

MIDWAY FIELD.

LOCATION.

The region commonly called the "Midway field," and so defined in this report, embraces the belt of territory along the northeastern base of the Temblor Range, beginning in the eastern part of T. 31 S., R. 22 E., and extending in a southeasterly direction as far as the south line of T. 32 S., Rs. 23 and 24 E., which marks the change from the Mount Diablo to the San Bernardino base and meridian. It includes the eastern part of T. 31 S., R. 22 E.; the southeastern portion of T. 31 S., R. 23 E.; practically the whole of T. 32 S., R. 23 E.,

with the exception of the southwestern corner; and the southwest corner of T. 32 S., R. 24 E.

GEOLOGY.

OUTLINE OF STRATIGRAPHY.

The formations involved in the geology of the developed Midway field include between 3,000 and 5,000 feet of siliceous and clayey shale, containing numerous thin calcareous layers and concretions, of Monterey or lower middle Miocene age; about 1,000 feet of softer, lighter-colored diatomaceous shale, in which are intercalated prominent lenses of coarse granitic sand and conglomerate (the latter containing some bowlders up to 6 feet in diameter) believed to be of Santa Margarita(?) or upper middle Miocene age; a series of at least 1,200 feet of soft sands, clays, and conglomerates believed to be of upper Miocene age, though possibly extending upward into the Pliocene, and assigned to the McKittrick formation; and, finally, stream deposits and alluvium of Recent age. The Santa Margarita(?) and Monterey formations are apparently conformable, while the McKittrick (upper Miocene) overlies these unconformably.

The oil is believed to have originated in the diatomaceous shales of the Monterey and Santa Margarita(?) and to have migrated to either the porous layers included in these formations or to the sands and gravels of the unconformably overlying McKittrick. The productive sands in all the operating wells are included in the base of the McKittrick except, possibly, the deeper sands in some of the wells in the northern part of the field, which may occur in the Santa Margarita (?).

STRUCTURE.

The Midway field is on the monocline on the northeast flank of the Temblor Range. Two subsidiary folds, the Midway and Spellacy Hill anticlines, are developed on the flanks of this monocline. The Midway anticline may be traced on the surface from sec. 36, T. 31 S., R. 22 E., to the western part of sec. 8, T. 32 S., R. 23 E. Evidence offered by the well logs indicates that the anticline continues as far southeast as the northeastern part of sec. 17 in the last-mentioned township, and may possibly here coalesce with the Spellacy Hill anticline. The Spellacy Hill anticline may be traced on the surface, and also in the wells in the developed territory, from the eastern part of sec. 18, T. 32 S., R. 23 E., through the southern part of sec. 17, across the southwestern corner of sec. 16, diagonally through sec. 21, through the southern part of secs. 22 and 23, across secs. 25 and 26, T. 32 S., R. 23 E., and thence with a course slightly south of east out across sec. 31, T. 32 S., R. 24 E., for an indefinite distance toward the Midway Valley. The axes of both anticlines are more or less undulating, and the dips on their flanks vary usually from 5° to 25°, as indicated on the map (Pl. III).

EFFECT OF STRUCTURE ON PRODUCTION.

Incomplete as are the data in hand, they show that the best production and the lightest oil come from the territory adjacent to the nodes of the anticlinal axes, especially near that node which marks the beginning of the plunge of the axis toward the Midway Valley. This fact suggests that the accumulation of oil in this field is possibly controlled, in part at least, by water. The details of structure in the developed territory are shown by contours on Plate III.

OIL SANDS.

General statement.—Less regularity marks the occurrence of the oil sands in the Midway field than in any other in the San Joaquin Valley so far examined by the writers. As a result it has been impossible to make any but tentative correlations for certain parts of the field, and future development may necessitate a revision of portions of the map.

Zone B.—Zone B, the top of which is indicated by contours on Plate III, varies in thickness from 10 to over 800 feet in the wells, the maximum thickness including several intercalated barren sands and shales. Little regularity in the variation is indicated by the logs, although in general the productive beds are apparently more uniform toward the southeast and somewhat thicker toward the middle of the field. The oil sands consist mostly of medium to coarse pebbly quartz sands which sometimes carry cobbles as much as several inches in diameter. Although accompanying the oil in small quantities in most of the wells, the sand is not very troublesome, except in a small area in the southeastern part of the field. This paucity of sand is doubtless due to the lack of gas pressure rather than to the coherency of the containing rock. The most productive sand toward the northwestern part of the area mapped on Plate III is found at depths varying from 250 to over 800 feet below the top of the zone (B) contoured on this map. In the northwestern part of sec. 6, T. 32 S., R. 23 E., the most productive sand is about 265 feet below the top of zone B; in the southern part of sec. 5, T. 32 S., R. 23 E., the most productive sand is 835 feet below the sand mapped as the top of zone B; and in the central part of sec. 31, T. 31 S., R. 23 E., the rich oil sand is about 400 feet lower than the top of zone B.

Zone A.—Throughout the greater part of the field, with the exception of a small area in the southeastern portion, the petroliferous zone (zone A) above zone B contains sands carrying oil in commercial quantities, especially toward its base. In addition to the oil sands, there are tar and gas sands, all separated by more or less important partings of clay and shale. The individual tar and oil sands vary in thickness from 5 to 70 feet, while the main part of the zone seldom extends for more than 200 to 300 feet above the top of zone B. Iso-

lated tar and gas sands are encountered in some of the deeper wells as much as 1,000 feet above zone B. The character of the sands in zone A is similar to that of the sand in zone B, being largely coarse pebbly quartz sands with occasional cobble layers.

Beds above zone A.—For about 400 feet above the top of zone A the shale predominates, while above the shale zone sands and pebble and cobble layers are the more important. Water sands and occasional tar or gas sands are encountered in the shale above the petroliferous zones.

Beds below zone B.—The beds below zone B consist almost entirely of blue and brown shale with occasionally intercalated sand streaks or lenses carrying water or petroleum. Traces of petroleum are said to occur in the shale for a considerable distance below zone B in one of the wells in the northwestern end of the field. Productive sands have recently been encountered in the shales below zone B. Water sand has been found immediately below zone B in some of the wells that have penetrated through this latter zone.

WATER SANDS.

The strata above the petroliferous zones carry less water in this field than in any other so far studied on the flanks of the Temblor Range. The accumulations of water in this part of the formation are usually most pronounced at the base of the sandy zone—that is, about 400 feet above the top of zone A or 600 feet, more or less, above the top of zone B. The wells toward the central part of the area encounter more water as a rule than those farther southeast. The water sands are usually coarse and in many places contain pebbles and cobbles; they vary in thickness from 10 to over 100 feet, as penetrated by the wells.

Water also occurs just above or associated with the upper sands of zone A, intercalated in the shale and clay between zones A and B, and immediately below zone B. These sands in the petroliferous zones are usually coarse and vary from 5 to 20 feet in thickness. Upon the proper understanding and handling of the waters in the sands in the oil-bearing zones depends the future welfare of this field.

Practically all the waters encountered in the field are more or less mineralized, often with salt and sulphur. The capacity of those wells which are utilized for water is said to range as high as 1,200 to 2,500 barrels per day.

PRODUCT.

The oil in the Midway field varies from black to brown in color, and in gravity from about 11° or 12° to as high as 20° or 22° Baumé. The heavier oil as a rule comes from the sands in the basal part of zone A, and in the shallowest wells (those near the axis) from the

sands in zone B. The lighter oil comes from zone B, usually from the wells that are deeper, but still not far from the axes of the anticlines. Gas accompanies the oil in all the wells, but except in a few near the axis in the southeastern portion of the field it is not under the strong pressure that affects it in the Sunset field. As a result of this low gas pressure little sand accompanies the oil except in rare instances.

PRODUCTION.

Lack of means of transport until quite recently has precluded the proper testing of the wells, so that little can be said as to their ability to produce under continued operation. Initial productions at the rate of 2,500 barrels or more per day have been reported for two or three wells in the field, but the individual average for the whole territory is believed to be less than 100 barrels per day. The production is greatest in the southeastern part of the field, where it is not uncommon for wells to make from 150 to 250 barrels per day; toward the west-central part of the field the wells so far tested will not average more than 50 to 100 barrels. The low production as compared with other fields is believed to be due largely to lack of gas pressure, rather than to thinness of sands. Such a theory leads to the conclusion that the wells will be long-lived, with a fairly uniform rate of production.

METHODS.

The productive wells vary in depth from 500 to over 2,800 feet, and practically all secure their oil by pumping. The method of handling the water is interesting, and is described in more or less detail under each area. The conditions are so varied that each well usually has to be handled somewhat differently from the others, even from its nearest neighbor.

LOCAL AREAS OF MIDWAY FIELD.

UNION–BROOKSHIRE–HAWAIIAN AREA.

Location.—The area denoted by the heading embraces the eastern half of the northern part and the eastern one-third of the southern part of T. 31 S., R 23 E. It includes wells now drilled or being drilled by the Union, Bear Creek, Majestic, Brookshire, Pioneer Midway, California Midway, Chanslor-Canfield Midway (Santa Fe Railway), Hawaiian, Mays, and several other oil companies.

Underground geology and production.—Development in this area has all taken place since the preparation of the main part of this bulletin, and all of the following notes concerning the area have been added as the report is going to press. The wells vary in depth from about 1,000 to over 2,800 feet and penetrate from 25 to 200 feet of productive sand. The sand is usually coarse and consists largely of water-worn granitic material. Tar sands are en-

countered in the wells intermittently from about 800 feet below the surface downward to the productive zone. In some of the deeper wells the uppermost tar sands are as much as 1,500 feet above the top of the productive zone. Water sands usually occur between the uppermost tar sands and the productive measures. The oil varies in gravity from 13° Baumé in the northern part of the area to 19° in the southern part. Oil claimed to be of 20° to 25° Baumé gravity is found in the shale above the most productive sands. Only two or three wells in the area have been properly tested and one of these is now flowing more than 2,000 barrels per day. Extravagant claims of extraordinary production based upon temporary initial flows have been made for several of the wells but until these wells are actually tested nothing definite regarding them can be known.

OREGON MIDWAY—SANTA FE—LOCKWOOD AREA.

Location.—The area denoted by the heading embraces the northwestern part of the developed Midway field, and consists of the southern edge of sec. 31, T. 31 S., R. 23 E., and secs. 5, 6, 7, 8, 9, 15, 16, and 17, T. 32 S., R. 23 E. It includes the wells operated by the Midway Crude, Midway of Oregon, Santa Fe Railway, and Lockwood oil companies, and occupies the flanks of the Temblor monocline and of the subsidiary Midway anticline where it merges into the monocline.

Zone B.—There is less regularity in the sands comprising zone B and also in the other strata of this area than in the beds of any other field so far studied in detail on the flanks of the Temblor Range. As a result it has been impossible to locate the top of zone B with certainty in many of the wells of the area. Tracing the oil sands from the region of sec. 22, T. 32 S., R. 23 E., where zone B is easily recognized, it has been possible to locate what is believed to be the equivalent of this zone in most of the wells, and as the horizon at which this occurs is checked by the other criteria used in correlation, this horizon has been mapped by contours on Plate III.

Zone B, as penetrated by the wells, varies in thickness from 10 or 15 feet to about 800 feet, this latter figure doubtless including intercalated barren strata or partings, of which several are usually indicated in the logs showing the details of the zone. No regularity has been recognized in the variation in thickness of the zone, logs showing maximum and minimum figures being found in various parts of the area. This variation is doubtless due in part to the personal factor introduced by the drillers.

The sands of zone B consist mostly of coarse quartz grains and generally carry pebbles and in many places cobbles of considerable size. Although the sand is more or less incoherent, very little accompanies the oil, owing to the low gas pressure in this part of the field.

The partings in the zone and the beds immediately above and below it are of blue clay or shale or hard sand shell. Water is found below it in most of those wells that penetrate many feet below its base.

Zone A.—As is the case in the area next southeast, zone A consists of a number of sands carrying oil, often in commercial quantities. Zone A proper usually includes strata for 200 or 300 feet above the top of zone B, although beds showing traces of oil and gas are encountered as high as 600 feet above the latter. The sands in zone A are similar in composition and grain to those of zone B and are separated by partings of shale and shell. Zone A is separated from zone B by 30 to nearly 200 feet of blue or brown shale, this shale stratum being fairly regular in thickness and persistent throughout the southeastern portion of the area. So far as known, no well now in operation derives its supply solely from zone A, so that statements concerning the properties of its oil are meager. The oil is known to be heavier than that found in zone B, and little gas accompanies it. Water sands occasionally occur intercalated in zone A, and also commonly in the strata between it and zone B, the latter case being especially noticeable in some of the wells in the northwestern portion of the area.

Beds above zone A.—The beds for about 400 feet above the top of zone A consist of blue shale, with minor quantities of sand often carrying traces of oil and gas. Above the shale zone the strata are largely coarse or pebbly sands and sometimes cobble-bearing layers. Water is sometimes encountered in sands in the beds above zone A.

Beds below zone B.—The beds below zone B consist largely of blue and brown shale and sandy shale usually showing traces of oil. Any coarse sands immediately below zone B are liable to carry water.

Water sands.—Most of the underground water in this area occurs either associated with or below the petroliferous zone. Surface waters are encountered in some of the wells in coarse sands varying in thickness from 10 to over 100 feet, usually at the bottom of the sandy zone about 400 feet above the top of zone A. Water also occurs associated with the tar and oil sands of zone A, and also in the beds between zones A and B in layers of coarse sand from 10 to 20 feet thick, especially in the northwestern portion of the area. Where water occurs in zone A, the thickness of the nonpetroliferous strata between zones A and B is usually much greater than where no water occurs in zone A. This is doubtless due to the water driving the hydrocarbons out of the strata in which it collects.

The water from the well in the northeast corner of sec. 7, T. 32 S., R. 23 E., is believed to come from a sand in the top of zone A. The abundance of water at this particular locality, amounting to 2,500 barrels per day, is peculiar, as no such amounts are found in adjacent wells, although what is believed to be the same horizon is encountered

in them. The water from this well is fairly good and is used for domestic and other purposes throughout the Midway district.

Water is known to occur in sands immediately below the base of zone B in some of the wells, and is believed to be present at the same horizon throughout a large part of the area, although care in drilling has avoided penetrating it in most of the wells so far put down.

It is reasonable to suppose that as development progresses toward the northeast and down the dip of the strata, water will be found more and more abundant in the petroliferous as well as the other zones, but it is the belief of the writers that the increase in the water will tend to concentrate the petroleum into narrow isolated beds without materially decreasing its amount.

Product.—The wells in this area yield black to brown oil varying in gravity from 12° to 20° Baumé. The heaviest oil comes from the southeastern part, the lightest from the deeper wells in sec. 8, while oil of about 16° to 17° Baumé comes from the northern part and many of the wells in the central part. The oil in zone B is known to be lighter than that in zone A. Little sand and usually not much gas accompanies the oil.

Production.—Little definite information is at hand relative to the productiveness of the wells in this part of the field. Initial flows of as much as 2,500 barrels per day are known to have occurred. Those wells that have been pumped for a considerable time yield little over 100 barrels each per day.

Methods.—The wells in this area vary in depth from about 900 to over 2,300 feet and all obtain their oil by pumping. The manipulation of the casing differs from well to well, but in general it may be said that the first string is landed between zone A and zone B in the shallower wells, and at or near the top of zone A in those a little deeper.

Typical logs.—A typical log for the northern part of the area is as follows:

Log of well in the NW. ¼ sec. 8, T. 32 S., R. 23 E.

	Feet.
Yellow sandy clay	290
Coarse gravel	310
Reddish sand	375
Sandstone	385
White sand	400
Light-brown clay	405
Dark oily brown clay	410
First oil sand	430
Dark-blue shale	730
Light-blue sandy shale	820
Hard shell	823
Oil sand (top of zone A, proper)	835
Sandy blue shale	840
Water sand	845

	Feet.
Blue clay (water off 11⅝ inches at 852)	853
Hard shale, gray stone	858
Blue shale and blue clay streaks	865
Some sandy, small shale pebbles	865
Water sand and water	870
Brown shale	875
Oil sand	880
Blue shale and fine gravel	895
Hard gray shell	898
Oil sand and oil (good)	905
Sandy blue shale and fine sand	915
Hard shell	920
Coarse water sand	950
Sandy blue shale	960
Fine blue shale	964
Blue clay	980
Blue shale (sandy shell at 985)	985
Water sand	990
Blue shale	1,000
Fine blue clay (landed 9⅝ inches at 1,007 and water off)	1,025
Sticky blue shale	1,035
Blue shale and shell	1,050
Blue shale	1,070
Blue clay	1,085
Blue shale	1,095
Brown shale	1,110
Oil sand (producing), top of zone B	1,134
Shale and blue clay	1,137
Oil sand (producing)	1,149

A characteristic log in the south-central part of the area is as follows:

Log of well in the NE. ¼ sec. 17, T. 32 S., R. 23 E.

	Feet.
Clay and surface formation	174
Clay	186
Pink sand	235
White sand	275
Oil sand	287
Blue clay	332
Shale	426
Dry oil sand	432
Shell and shale	680
Oil sand (top of zone A)	701
Shell and shale with oil	747
Oil sand and cobbles	788
Shell and shale with oil	815
Oil sand	826
Shale with oil	857
Oil sand	870
Blue clay	890
Oil sand (top of zone B)	895
Shale with oil	905
Oil sand	908

	Feet.
Shale	918
Oil sand	925
Shale	935
Oil sand	960
Shale	1,065

A typical log in the southern part of the area is as follows:

Log of well in SW. ¼ sec. 16, T. 32 S., R. 23 E.

	Feet.
Surface	150
Clay and sand	385
Water sand	393
Blue clay	400
Water sand	410
Blue clay with streaky sand	840
Clay, showing of oil	970
Sand	995
Clay	1,045
Oil sand	1,225

FAIRBANKS–BURKS–MOUNTAIN GIRL AREA.

Location.—This area comprises the southeastern part of sec. 16, the whole of secs. 14, 15, 21, and 22, and all of sec. 23 except the southeastern corner, in T. 32 S., R. 23 E. It includes wells operated by the following companies: Santa Fe Railway (secs. 15 and 21), Fairbanks, Burks, Arminta, Bay City, Gypsy, Mountain Girl, Producers Guaranteed, Knob Hill, and Babcock (formerly Josephine). The area lies on the flanks of the Spellacy Hill anticline, mostly on the southeast side of the axis.

Zone B.—Two fairly well-defined productive oil zones are encountered in most of the wells in this area, the lower one, zone B, being the most productive. Zone B varies in thickness in the wells from 15 to over 100 feet, the latter figure doubtless including intercalated barren sands and shale, of which there are usually one or more throughout the zone; the best producers usually tap from 15 to 50 feet of sand. The zone differs greatly from well to well and little correspondence in the logs can be noted except in a most general way. The sands of zone B usually consist of medium to coarse-grained quartz sand which, in some places in the central part of the area, carries pebbles and cobbles of granite or other similar crystalline rocks. The sand is incoherent, and more or less of it accompanies the oil in most of the wells.

Zone A.—The zone above zone B that in other areas is usually characterized by tar and gas sands contains layers carrying oil in commercial quantities in some of the wells in the territory under discussion. It is true the oil is rather heavy, usually ranging from 11° to 13.5° Baumé, and the production is never over 30 to 50 barrels per day, but the product is worth saving, and for this reason the water

should be so handled in the wells as to protect these upper sands. Zone A comprises about 200 to 300 feet of strata above the top of zone B, and usually consists of several well-defined oil sands, each varying from 5 to 60 feet in thickness and separated by partings of blue or brown shale. The lowest sand in zone A is usually separated from the top of zone B by 50 to more than 200 feet of blue clay. In the northwestern part of the area water sand occurs in this blue clay. The sands of zone A are similar to those of zone B, consisting largely of quartz sand sometimes carrying pebbles and cobbles. Judging by some of the logs of wells in the northwestern part of the area, the line of separation of zones A and B is not as well defined in this region as in the territory farther southeast.

Beds above zone A.—The beds immediately above zone A consist largely of blue shale with minor amounts of sand, in one or more layers of which water and sometimes a little tar is encountered; from about 400 feet above the top of zone A upward the formation is mostly sand with less important shale layers.

Beds below zone B.—No log of a well in this area which passed far below zone B was available to the writers in their study, so that definite statements are impossible. The surface conditions, however, indicate that the beds below the productive zone consist largely of blue and brown shale, in which it would not be surprising to find isolated oil or water sands. Water sands immediately underlie zone B in most of the wells that penetrate through the productive zone.

Water sands.—Water is very troublesome in many of the wells in this area, and unless its occurrence is carefully studied and the wells are properly handled, it will ruin much of the territory that otherwise ought to be productive. Water occurs in sands just above or associated with the upper layers of zone A in some of the wells, especially in the southeastern part. Water occurs also just below zone B both in the southeastern and central portions, and in sands between zones A and B in the northeastern end. The distribution of the water sands is irregular and the behavior of the water different in each of the wells. The water sands above zone A vary in thickness from 15 to 50 feet and yield highly mineralized water, often with salt and sulphur; the sand between zones A and B lies 10 feet or more below the lowest bed in zone A and is 4 or more feet in thickness; the water sand below zone B is separated from it by 5 to 30 feet of clay or shale, is 30 feet more or less in thickness, and yields salt water, as much as 700 or 800 barrels per day, it is said, coming from it in one well in the northern part of sec. 26.

Product.—The product of zone B is a black oil varying in gravity from about 13.5° Baumé in the shallower wells at the northwestern end of the area to 17° or 19.5° in the deeper wells in the southeastern end. Some sand accompanies the oil in a few of the wells, especially

toward the southeast end of the area, but as a rule little difficulty is experienced as compared with that in the next area southeast. The oil from the sands of zone A is black and heavier than that from zone B, varying in gravity from 12.8° to 15° Baumé. Gas in moderate quantities occurs with the oil and also in isolated sand lenses throughout zone A.

Production.—The production of the wells tapping zone B varies from 50 to over 250 barrels per day per well; that of wells deriving their supply from zone A varies from 10 to possibly 50 barrels per day. One well near the middle of the line separating secs. 23 and 26, passing through zone B into the water sand, is said to have yielded 700 or 800 barrels of water and 20 barrels of 14° Baumé oil per day. As zone B yields oil of 15° to 19° Baumé in other wells in the same locality, the low grade yielded by the water-contaminated well is accounted for by the deleterious effect of the water on the oil.

Methods.—The productive wells in this area vary from 500 to about 1,600 feet in depth; some untested wells are much deeper than this, but so far no authentic data concerning them have been obtained. The question of the water associated with the oil zones is a serious one for this area. Great care should be used in shutting off the water lying above or associated with the upper beds of zone A, else this water may follow down the casing and penetrate the sands of zone A, which, though they may not be utilized in the particular well yielding the water, should be preserved for adjacent wells in which the oil of zone A may be of commercial importance. Furthermore, wells which shut off the water above zone A, but pass through this zone without utilizing any of its sand and then go into the water sand between zones A and B, should isolate the sands of zone A, either by landing a string of casing between them and the water sand below or else by thoroughly cementing off the water in the lower sand. The suggestions above mentioned are for the protection of the productive sands of zone A; similar precautions should be taken in reference to zone B by shutting off the water where it occurs above and below it (if tapped).

Typical logs.—A log typical of the northwestern end of the area is as follows:

Log of well in NW. ¼ sec. 22, T. 32 S., R. 23 E.

	Feet.
Yellow surface formation, largely sand	300
Blue clay and shale	530
Oil sand, traces of 15° Baumé oil and some gas	540
Blue clay, shale, and sand	700
Oil sand, traces of oil or tar	705
Blue clay and shale, minor amounts of sand	1,365
First oil sand, 30 to 50 barrels per day of 12.8° oil (zone A)	1,406
Yellow and brown clay	1,416

	Feet.
Water sand, with water rising to 1,300 feet	1,420
Blue clay	1,520
Second oil and sand (zone B)	1,535+

A characteristic log of the central part of the area is as follows:

Log of well near middle line between secs. 22 and 23, T. 32 S., R. 23 E.

	Feet.
Sand and gravel	200
Yellow clay	240
Clay and water	245
Hard sand and clay	300
Blue shale	316
Yellow sand	376
Soft sand (gray)	391
Blue shale (sandy)	426
Yellow sand	451
Gray sand	481
Blue shale	514
Tar sand	519
Blue shale (sandy)	599
Blue shale	625
Hard shell	628
Blue shale (with hard shells)	750
Blue clay	825
Hard shell	830
Blue shale	968
Tar sand	973
Blue shale	1,088
Brown shale	1,093
Hard shell	1,098
Oil sand	1,113
Brown shale	1,123
Oil sand	1,168
Blue shale	1,173
Oil sand	1,233
Blue shale	1,308
Brown shale	1,383
Oil sand (rich)	1,398
Hard shell	1,401
Black shale	1,433
Hard shell, water below lots of it, and salt, in a coarse water sand	1,465

A typical log of the area near the axis of the Spellacy Hill anticline is as follows:

Log of well in central part of the S. ½ sec. 22, T. 32 S., R. 23 E.

	Feet.
Bed gravel	50
Blue clay	400
Gray sand	415
First indication of oil	425
First oil sand	430
Blue clay	440
Second oil sand	490

	Feet.
Third oil sand	540
Shale and blue clay	590
Dry oil sand	600
Sand and gas	615
Brown shale over sticky sand, thin layer of sand, with gas at 660; more gas at 700.	1,100
Oil sand	1,105
Brown shale	1,400

BABCOCK—MASCOT—TWENTY-FIVE AREA.

Location.—This area comprises the southern part of secs. 23 and 24, the whole of secs. 25 and 26, T. 32 S., R. 23 E., sec. 30, T. 32 S., R. 24 E., and the territory adjacent to these. It includes, among others, properties operated by the following companies: Babcock (formerly Josephine), Talara, Santa Fe Railway (sec. 24), Mascot, Opal, Safe, Altoona, Crœsus, Twenty-five, Paraffine, and Standard. The area is almost entirely on the northeastern flank of the Spellacy Hill anticline, adjacent to where it bends from a southeasterly to an easterly trend and fades off into the Midway Valley.

Zone B.—The more productive strata of the area occupy a zone (zone B) varying in thickness, as penetrated in the wells, from 11 to about 150 feet, the greater thickness usually including more or less intercalated shale and barren sand. In some of the wells, however, a thickness of over 100 feet of continuous productive sand is reported. The sand is generally medium to coarse grained, and consists of grains of quartz with minor amounts of other minerals. Cobbles and pebbles occur in the oil zone in the wells, especially in the northwestern part of the area. Near the southeastern edge of the area the productive measures consist of two or three sands, the lowest being the richest and carrying the lightest oil.

Zone A.—Beds or lenses more or less impregnated with oil or tar, and usually containing gas, are intercalated in the shale and sand strata above the top of the productive zone. In some of the deeper wells these tar sands occur 1,000 feet or more above zone B, while in the shallower ones zone A is seldom over 500 feet in thickness in the wells, and often consists of but one or two impregnated sands. The individual tar sands are 5 to 70 feet thick, and little uniformity is to be noted in the sands of adjacent wells, owing to the local lenslike occurrence of the strata, and in part also, no doubt, to the personal factor brought in by the drillers reporting the logs. The most persistent tar sands overlie zone B, usually separated from it by shell or shale varying from a mere parting to 40 feet or more in thickness. Many of these sands in the base of zone A contain more or less oil, some even enough for commercial exploitation. The sands vary from medium to coarse grained quartz, and sometimes carry pebbles and cobbles. Water is not reported as associated with any of the tar sands in zone A, although in one instance an

isolated tar sand occurs above a water sand. Water usually marks the top of the zone.

Beds above zone A.—The beds above zone A consist of alternating shale and sand layers, with occasional strata of pebbles and cobbles. The sand beds seem to predominate, more especially in the upper part of the series.

Beds below zone B.—Only a few wells in the productive area have completely penetrated zone B, and these, with one exception, have stopped in the water sand that lies below zone B. A well on the southwestern flank of the Spellacy Hill anticline, after being drilled through zone B, encountered brown shale with occasional sands, one of which contained a trace of oil.

Water sands.—Very little water is encountered in the strata above zone A, the comment in one log being that, although water was present, there was not enough to drill with. The water zone lies from a few feet above the top of zone A to near the surface; the sands are 5 to 50 feet thick, and in composition vary from coarse to pebbly quartz sand. The water is always highly mineralized.

Water occurs below zone B in several wells, and is believed to occupy a similar position below those which do not completely penetrate the productive sand. One well near the northwestern end of the area is said to be capable of yielding 700 to 800 barrels of good boiler water a day, the source of the water being uncertain, although it is believed by the operator that the water comes from below or possibly between the sands of zone B, as oil in small quantities accompanies the water.

Product.—The yield in the vicinity of Spellacy Hill varies from black oil of 14° Baumé gravity to brown oil of 20° to 22° Baumé. In general the heavier oil of 14° to 16° Baumé gravity occurs in the wells nearest the axis of the anticline, while the lighter oil comes from the deeper wells some distance away from it. The western part of the NW. ¼ sec. 25 includes an area in which the oil is particularly light, ranging from 17° Baumé in some of the Twenty-five wells to 22° in the Altoona well. It is the belief of the writers that this lighter oil occupies a particular lens of sand which extends throughout a more or less limited area, and that even within this particular lens the oil varies from place to place. Sand accompanies the oil in considerable quantities in the area near the anticline, especially in the northwestern portion. Gas pressure is also strong in the same general area and occasionally in the deeper wells.

Production.—The production of the individual wells varies from 8 or 10 barrels per day in the wells on the southwest side of the anticline to 300 barrels in the best producers. One of the best wells in the northern part of the area is said to have started with a production of over 500 barrels per day; at the end of a year it was giving about

250. The average for the better wells in sec. 25 is between 150 and 250 barrels per day. Only two or three of the more gassy wells flow, the others being pumped.

Methods.—The productive wells in this area vary from about 800 to 1,800 feet in depth. Water is usually shut off in the blue clay just above zone A. Where the wells have inadvertently penetrated the water sand under zone B, the well is usually plugged up to the base of the productive sand and then perforated from that point upward. It has been found best to pump certain of the wells in which the sand is bothersome only two or three hours each day.

Typical logs.—A typical log of one of the wells not far from the axis of the anticline in the southeastern part of the area is as follows:

Log of well in middle of the W. ½ sec. 25, T. 32 S., R. 23 E.

	Feet.
Brown sand	250
Blue clay	425
Clay	500
Gray sand, dry	597
Hard sand, shell, some gas, heavy asphalt oil	600
Muddy sand, light blue	622
Blue shale	624
Dry oil sand	628
Sheets of mud shale and asphalt sand	725
Blue clay	732
Clay, hard shell	735
Asphalt sand	738
Thin strata of dry oil sand and shale	755
Hard brown sand, stained with oil	773
Shale and loose dry oil sand	785
Sheet of shale and hard gray sand	835
Blue shale	855
Light-colored gray shale	865
Hard gray sand	895
Blue clay	910
Oil sand, show of oil	915
Strata of shale and gray sand	965
Muddy sand, showing brown oil	1,080
Thin blue clay	1,095
Soft muddy sand	1,105
Gray shale	1,110
Oil sand	1,113
Gray shale	1,117
Oil sand	1,120
Gray shale, strata of dry sand and gas	1,151
Hard gray sand and shell	1,154
Close hard gray shale	1,160
Some gas, close solid oil sand, good show of oil	1,168
Light traces of shale in close oil sand	1,190
Hard sand shell; big gas strata; blew water out of hole over derrick roof	1,194
Very rich soft oil sand	1,202
Close bed of oil sand	1,212

	Feet.
Very rich soft oil sand	1,222
Very hard shell	1,224
Rich soft oil sand; bottom of this streak looks a little heavier	1,257
Soft and hard streak; rich oil sand, light gravity	1,326
Hard sand shell	1,335
Brown shale.	

A log of one of the deeper wells along the northeastern edge of the tested territory is as follows:

Log of well in southern part of sec. 24, T. 32 S., R. 23 E.

	Feet.
Sand	130
Clay	200
Conglomerate	295
Blue clay	330
Sand	445
Shale	454
Blue clay	615
Hard sandy shell	628
Clay	638
Hard shale	648
Clay	662
Hard shale	713
Clay	721
Hard shale	810
Clay	818
Hard shale, clay and shell	1,200
Oil sand (not much oil)	1,215
Shale	1,234
Sand	1,265
Clay	1,270
Hard shell	1,298
Sand (more water)	1,310
Clay and few shells	1,491
Shale and clay	1,557
Oil sand, shows much oil and gas	1,567

ARCATA—MONTE CRISTO- SUNSET MONARCH AREA.

Location.—The area denoted by the heading, the southernmost in the Midway field, comprises secs. 31 and 32, T. 32 S., R. 24 E., the eastern part of the fractional sec. 27, the whole of fractional sec. 26, T. 12 N., R. 24 W., and the territory immediately adjacent to these. It includes among others the wells of the Arcata, Monte Cristo, Fort Wayne, Union, Stratton, Nanticoke (now Union), and Sunset Monarch oil companies. It lies in the region where the Spellacy Hill anticline merges into the flank of the Thirty-five and California Fortune anticlines.

Zone B.—Insufficient data are at hand to warrant many definite statements concerning the underground geology in this area. Zone

B lies about 1,200 to over 1,600 feet below the surface in the wells the logs of which were examined. It consists of the usual coarse quartz sands carrying pebbles. The productive zone consists of three separate thin sands within a thickness of about 100 feet, or, elsewhere, one or two somewhat thicker sands within about 60 feet. Tar and poorly productive sands in some places form a zone 100 to 300 feet thick immediately overlying the productive sands (zone B). These tar sands are interbedded with barren shales and rarely with water sands.

Zone A.—A zone of tar sands from 10 to about 100 feet thick lies 300 to 400 feet above the top of zone B. The individual sands, of which there are one to three in the different wells, are 10 to 30 feet thick in the wells, and consist of coarse quartz sands.

Beds above zone A.—The beds above zone A consist of sand and blue shale with occasional gravel layers, especially near the surface.

Beds below zone B.—The only well which has apparently penetrated entirely through zone B encounters blue shale with intercalated hard shells and occasional traces of oil for at least 200 feet below the base of zone B.

Water sands.—Two to seven water sands occur above the top of zone A, and in one well a water sand 10 feet in thickness occurs between the top of the horizon of the tar sands and the top of the tar sand immediately overlying the productive zone B. In another well water is reported between two tar sands about 100 feet above zone B. These sands are coarse but yield little water.

Product and production.—The product of the wells in this area is most variable, one well yielding heavy oil of 11½° or 12° Baumé gravity, while another is said to yield oil considerably lighter. The individual wells produce from 30 to 50 barrels per day, although it must be admitted that none of the few put down have yet been thoroughly tested.

BUENA VISTA HILLS AREA.

Location.—The Buena Vista Hills area embraces the Buena Vista Hills, which lie largely in the southeastern part of T. 31 S., R. 23 E., and the northern part of T. 32 S., R. 24 E. Among the companies operating in this area are the Standard and the Honolulu.

Wells.—Only two wells have been drilled in this area. One drilled by the Honolulu Oil Company in the SE. ¼ sec. 10, T. 32 S., R. 24 E., encountered a terrific gas pressure in sand at a depth of a little over 1,600 feet and a 200 to 500 barrel flow of oil at about 2,600 feet. The Standard Oil Company drilled a well in the SW. ¼ sec. 26, T. 31 S., R. 23 E., which also encountered ~~a strong~~ gas flow at 1,725 feet. This gas has been confined and is now being used by the company for development purposes in other parts of the Midway district.

OIL COMPANIES AND OIL WELLS IN MIDWAY DISTRICT.

In the following list of wells and companies the locations refer to the Mount Diablo base and meridian. The elevations, which are approximate, are from the Atchison, Topeka and Santa Fe Railway, or taken by aneroid barometer.

Oil companies and oil wells in the Midway district.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Alpine	Bay City	1	NW. ¼ sec. 22, T. 32 S., R. 23 E	1,270
Do		2	do	
Do		3	do	
Altoona (W. T. & M.)		1	NW. ¼ sec. 25, T. 32 S., R. 23 E	1,465
Do		2	do	
Alvarado		1	NW. ¼ sec. 15, T. 32 S., R. 23 E	1,260
Do		2	do	
Amazon	Producers Guaranteed.	1	SW. ¼ sec. 22, T. 32 S., R. 23 E	1,350
Do	do	2	do	
Do	do	3	do	
Do	do	4	do	
Andrews. (*See* Oskaloosa.)				
Arcata. (*See* Santa Fe.)				
Arminta		1	NW. ¼ sec. 22, T. 32 S., R. 23 E	1,265
Do		2	do	
Babcock Petroleum	Josephine	1	SE. ¼ sec. 23, T. 32 S., R. 23 E	1,260
Do	do	2	do	1,390
Do	do	3	do	1,375
Do		4	do	
Do		5	do	
Do		6	do	
Do		7	do	
Do		8	do	
Bay City. (*See* Alpine.)				
Bear Creek		1	Sec. 14, T. 31 S., R. 22 E	1,330
Do		2	do	
Do		3	do	
Do		4	do	
Bedrock	Equitable Petr	1	SW. ¼ sec. 14, T. 32 S., R. 23 E	
B. H. & C	Hall & Barlow	1	NW. ¼ sec. 25, T. 32 S., R. 23 E	
Do	do	2	do	
Do	do	3	do	
Do	do	4	do	
Do	do	5	do	
Brocton		1	SW. ¼ sec. 23, T. 32 S., R. 23 E	
Brookshire		1	Sec. 24, T. 31 S., R. 22 E	1,234
Do		2	do	
Do		3	do	1,236
Do		4	do	
Burkes		1	NE. ¼ sec. 22, T. 32 S., R. 23 E	1,285
Do		2	do	1,340
Do		3	do	
Do		4	do	
California-Midway		1	NE. ¼ sec. 32, T. 31 S., R. 23 E	1,190±
Do		2	do	
Carbo-Petroleum		1	NW. ¼ sec. 26, T. 32 S., R. 23 E	
Do		2	do	
Casa. (*See* Jade.)				
Croesus		1	SW. ¼ sec. 25, T. 32 S., R. 23 E	1,635
Do		2	do	1,630
Do		3	do	1,610
Do		4	do	1,655
Do		5	do	1,645
Do		6	do	
Dayton		1	NW. ¼ sec. 9, T. 32 S., R. 23 E	1,280
Dixon. (*See* Knob Hill.)				
Drake & Yancy		1	S. ½ sec. 15, T. 31 S., R. 22 E	
Do		2	do	
Elkhorn		1	SE. ¼ sec. 25, T. 32 S., R. 23 E	1,260
Do		2	do	
Equitable Petroleum		1	NW. ¼ sec. 15, T. 32 S., R. 23 E	
Equitable Petroleum. (*See* Bedrock.)				
Fairbanks		1	NW. ¼ sec. 22, T. 32 S., R. 23 E	1,370
Do		2	do	
Do		3	do	
Fort Wayne. (*See* G. M. B.)				
France		1	NE. ¼ sec. 4, T. 32 S., R. 23 E	

Oil companies and oil wells in the Midway district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
G. M. B	Fort Wayne	1	SE. ¼ sec. 31, T. 32 S., R. 24 E.	922
Do	do	2	do	980
Do	do	3	do	
Graham, F. M		1	SE. ¼ sec. 25, T. 32 S., R. 23 E.	
Graham & Hall		1	NW. ¼ sec. 26, T. 31 S., R. 22 E.	
Greenlee Consolidated		1	NE. ¼ sec. 15, T. 32 S., R. 23 E.	
Griffith Crude	Producers Guaranteed.	1	NW. ¼ sec. 23, T. 32 S., R. 23 E.	
Gypsy		1	SE. ¼ sec. 22, T. 32 S., R. 23 E.	
Do		2	do	
Do		3	do	
Do		1	NW. ¼ sec. 23, T. 32 S., R. 23 E.	1,450
Do		2	do	1,290
Do		3	do	
Jolly Joker. (*See* Gypsy.).				
Hartford	Lockwood	1	E. ½ sec. 16, T. 32 S., R. 23 E.	
Do	do	2	do	1,500±
Hawaiian (Crandall-Matson).		1	N. ½ sec. 31, T. 31 S., R. 23 E.	1,328
Do		2	do	1,254
Do		3	do	1,242
Do		4	do	
Do		5	do	
Honolulu		1	S. ½ sec. 4, T. 32 S., R. 24 E.	
Do		1	SE. ¼ sec. 10, T. 32 S., R. 24 E.	
Do		1	Sec. 14, T. 32 S., R. 24 E.	
Do		2	do	
Do		3	do	
Jade	Casa	1	SW. ¼ sec. 15, T. 32 S., R. 23 E.	1,255 (?)
Do	do	2	do	
Do		1	NE. ¼ sec. 15, T. 32 S., R. 23 E.	
Knob Hill	Dixon	1	NE. ¼ sec. 23, T. 32 S., R. 23 E.	1,210
Do		2	do	
Do		3	do	
Do		4	do	
La Belle		1	SW. ¼ sec. 4, T. 32 S., R. 23 E.	
Do		2	do	
Lockwood		1	SW. ¼ sec. 16, T. 32 S., R. 23 E.	1,515
Do		2	do	1,460
Do		3	do	1,420
Do		4	do	1,440
Logan-Twitchel		1	SE. ¼ sec. 23, T. 31 S., R. 22 E.	
Do		2	do	
Majestic		1	W. ½ sec. 23, T. 31 S., R. 22 E.	
Do		2	do	
Manhattan-Midway	Stratton	1	SW. ¼ sec. 32, T. 32 S., R. 24 E.	840
Do	do	2	do	930
Marion	Stroud et al	1	SE. ¼ sec. 15, T. 32 S., R. 23 E.	
Mascot		1	NE. ¼ sec. 26, T. 32 S., R. 23 E.	1,450
Do		2	do	1,360
Do		3	do	1,340
Do		4	do	1,370
Do		5	do	1,310
Do		6	do	1,470
Do		7	do	1,345
Do		8	do	1,420
Do		9	do	
Do		10	do	
Do		11	do	
Do		12	do	
Do		13	do	
Do		14	do	
Do		15	do	
Do		16	do	
Do		17	do	
Do		18	do	
Do		19	do	
Mays		1	Sec. 28, T. 31 S., R. 23 E.	1,230
Do		2	do	
Do		3	do	
Do		4	do	
Do		1	SE. ¼ sec. 30, T. 31 S., R. 23 F.	1,214
Midland	Lockwood	1	NW. ¼ sec. 16, T. 32 S., R. 23 E.	
Do	do	2	do	
Do	do	3	do	
Do	do	4	do	
Do	do	5	do	
Do	do	6	do	
Midway Crude	Scott	1	S. ½ sec. 31, T. 31 S., R. 23 E.	1,316
Do		2	do	1,328
Midway of Oregon		1	NE. cor. SW. ¼ sec. 4, T. 32 S., R. 23 E.	1,100

Oil companies and oil wells in the Midway district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Midway of Oregon	Oriental	1	NW. ¼ sec. 8, T. 32 S., R. 23 E.	1,390
Do	do	2	do	1,375
Do	do	3	do	1,350
Do	do	4	do	1,400
Do	do	5	do	1,370
Do		4	NE. ¼ sec. 7, T. 32 S., R. 23 E.	1,600?
Do		1	SW. ¼ sec. 5, T. 32 S., R. 23 E.	1,325
Do		2	do	1,195
Do		1	SE. ¼ sec. 5, T. 32 S., R. 23 E.	1,2[illegible]0
Midway Queen		1	Sec. 22, T. 32 S., R. 24 E.	
Do		2	do	
Monte Cristo		1	NE. ¼ sec. 31, T. 32 S., R. 24 E.	1,075
Do		2	do	1,150
Do		3	do	996
Do		1	Sec. 32, T. 32 S., R. 24 E.	836
Do		2	do	856
Do		3	do	925
Do		4	do	830
Do		5	do	816
Do		6	do	
Do		7	do	
Moore	W. B.	1	SE. ¼ sec. 25, T. 32 S., R. 23 E.	1,315
Morse et al		1	SE. ¼ sec. 26, T. 32 S., R. 23 E.	
Do		2	do	
Mountain Girl		1	SE. ¼ sec. 22, T. 32 S., R. 23 E.	1,300
Do		2	do	1,480
Do		3	do	1,500
Do		4	do	
Do		5	do	
Do		6	do	
Mount Diablo		1	SE. ¼ sec. 25, T. 32 S., R. 23 E.	1,700
Do		2	do	1,685
New Richmond		1	SW. ¼ sec. 25, T. 32 S., R. 23 E.	1,390
Occidental	Santa Fe	1	NW. ¼ sec. 9, T. 32 S., R. 23 E.	
Occidental Queen	Moore	1	SE. ¼ sec. 25, T. 32 S., R. 23 E.	1,370
Opal	Sunset Coast	1	NW. ¼ sec. 25, T. 32 S., R. 23 E.	1,510
Do	do	2	do	
Oriental. (*See* Midway of Oregon.)				
Oskaloosa	Andrews	1	SE ¼ sec. 15, T. 32 S., R. 23 E.	1,150
Do	do	2	do	
Packard. (*See* Wilbert.)				
Packard & Tevis		1	NW. ¼ sec. 26, T. 32 S., R. 23 E.	
Do		2	do	
Paraffine		1	NE. ¼ sec. 25, T. 32 S., R. 23 E.	1,475
Do		2	do	1,490
Do		3	do	
Do		4	do	
Do		5	do	
Do		6	do	
Pierpont		1	SE. ¼ sec. 25, T. 32 S., R. 23 E.	1,440
Do		2	do	1,385
Do		3	do	
Do		4	do	
Do		5	do	
Do		6	do	
Pioneer Midway		1	Sec. 12, T. 31 S., R. 22 E.	1,258
Do		2	do	
Do		3	do	
Do		4	do	
Do		1	Sec. 18, T. 31 S., R. 23 E	
Do		2	do	
Do		3	do	
Do		1	Sec. 30, T. 31 S., R. 23 E.	1,258
Do		2	do	1,217
Do		3	do	
Do		1	Sec. 2, T. 32 S., R. 23 E.	
Do		2	do	
Do		3	do	
Do		4	do	
Do		5	do	
Producers Guaranteed		1	SW. ¼ sec. 23, T. 32 S., R. 23 E.	1,455
Do. (*See* Amazon.)				
Rico	Neptune	1	NE. ¼ sec. 25, T. 32 S., R. 23 E.	
Do	do	2	do	1,350
Do	do	3	do	
Do	do	4	do	
Do	do	5	do	
Do	do	6	do	
Do	do	7	do	
Safe		1	NW. ¼ sec. 25, T. 32 S., R. 23 E.	1,400
Do		2	do	

Oil companies and oil wells in the Midway district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Safe		3	NW. ¼ sec. 25, T. 32 S., R. 23 E.	
Do.		4	do.	
St. Lawrence		1	SW. ¼ sec. 5, T. 32 S., R. 23 E.	1,325
Do.		1a	do.	1,260
San Francisco Oil Co.		1	NE. ¼ sec. 27, T. 32 S., R. 23 E.	1,500
Santa Fe Railway		(?)1	S. ½ sec. 7, T. 32 S., R. 23 E.	1,600
Do.		(?)2	do.	1,500
Do.		1	Sec. 6, T. 32 S., R. 23 E.	1,460
Do.		2	do.	1,490
Do.		3	do.	1,380
Do.		4	do.	1,420
Do.		5	do.	1,400
Do.		6	do.	1,480
Do.		2	do.	1,366
Do.		1	S. ½ and NE. ¼ sec. 8, T. 32 S., R. 23 E.	1,350
Do.		2	do.	1,330
Do.		3	do.	1,440
Do.		4	do.	1,280
Do.		5	do.	1,310
Do.		6	do.	1,365
Do.		7	do.	1,410
Do.		8	do.	1,375
Do.		9	do.	
Do.		10	do.	1,270
Do.		11	do.	1,270
Do.		12	do.	1,290
Do.		13	do.	1,265
Do.	Sioux	1	NE. ¼ sec. 8, T. 32 S., R. 23 E.	1,268
Do.	do	2	do	1,370
Do.	do.	3	do.	1,320
Do.		1	W. ½ sec. 9, T. 32 S., R. 23 E.	1,200
Do.		2	do.	1,370
Do.		3	do	
Do.	Internois.	1	do.	1,290
Do.	Equitable Petr.	1	SE. ¼ sec. 14, T. 32 S., R. 23 E.	1,140
Do.	do.	2	do.	
Do.		1	E. ½ sec. 17, T. 32 S., R. 23 E.	1,550
Do.		2	do.	1,425
Do.		3	do.	1,515
Do.		4	do.	1,420
Do.		5	do.	
Do.		6	do.	1,415
Do.		7	do.	1,475
Do.		8	do.	1,452
Do.		9	do.	1,500
Do.		10	do.	1,448
Do.		11	do.	1,475
Do.		12	do.	1,470
Do.		13	do.	1,450
Do.		14	do.	1,448
Do.		(?)	do.	1,690
Do.	Spellacy	1	SW. ¼ sec. 15, T. 32 S., R. 23 E.	1,380
Do.		1	E. ½ sec. 18, T. 32 S., R. 23 E.	1,850
Do.		1	Sec. 21, T. 32 S., R. 23 E.	1,515
Do.		2	do.	1,380
Do.		3	do.	1,440
Do.		4	do.	1,500
Do.		5	do.	1,600
Do.		6	do.	1,380
Do.		1	S. ½ sec. 24, T. 32 S., R. 23 E.	1,330
Do.		2	do.	1,350
Do.	Arcata	1	NW. ¼ sec. 31, T. 32 S., R. 24 E.	1,190
Do.	do.	2	do.	1,185
Do.	Austin	1	NW. ¼ sec. 31, T. 32 S., R. 24 E.	
Do.		1	W. ½ and SE. ¼ sec. 25, T. 31 S., R. 22 E.	1,254
Do.		2	do.	
Do.		3	do.	
Do.		1	S. ½ sec. 4, T. 32 S., R. 23 E.	
Do.		2	do.	
Do.		1	E. ½ sec. 26, T. 31 S., R. 22 E.	
Do.		2	do.	1,650±
Do.		3	do.	
Sioux. (*See* Santa Fe Railway.)				
Scott, C. V. (*See* Midway Crude.)				
Scott et al.		1	Sec. 8, T. 31 S., R. 23 E.	
Sharp & Johnson		1	SW. ¼ sec. 6, T. 31 S., R. 23 E.	
Sheridan		1	Sec. 10, T. 31 S., R. 22 E.	
Do.		2	do.	

Oil companies and oil wells in the Midway district—Continued.

Name of company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Sheridan		3	Sec. 10, T. 31 S., R. 22 E.	
Do.		4	do.	
Standard.		1	Sec. 16, T. 31 S., R. 23 E.	
Do.		1	Sec. 22, T. 31 S., R. 23 E.	
Do.		2	do.	
Do.		3	do.	
Do.		4	do.	
Do.		1	Sec. 26, T. 31 S., R. 23 E.	
Do.		2	do.	
Do.		3	do.	
Do.		4	do.	
Do.		1	SW. ¼ sec. 1, T. 32 S., R. 23 E.	
Do.		1	N. ½ sec 10, T. 32 S., R. 23 E.	
Do.		1	E. ½ sec. 14, T. 32 S., R. 23 E.	
Do.		2	do.	
Do.	Talara.	1	SW. ¼ sec. 24, T. 32 S., R. 23 E.	1,390
Do.	do.	2	do.	1,400
Do.	do.	3	do.	1,395
Do.	do.	4	do.	1,290
Do.	do.	5	do.	1,250
Do.	do.	6	do.	1,190
Do.	do.	7	do.	1,115
Do.	do.	8	do.	
Do.	do.	9	do.	
Do.	do.	10	do.	
Do.	do.	11	do.	
Do.	do.	12	do.	
Do.	do.	13	do.	
Do.	do.	14	do.	
Do.	do.	15	do.	
Do.		1	Sec. 20, T. 32 S., R. 24 E.	
Do.		1	Sec. 28, T. 32 S., R. 24 E.	
Do.		2	do.	
Do.		3	do.	
Do.		4	do.	
Do.	Big Four.	1	Sec. 30, T. 32 S., R. 24 E.	1,160
Do.	do.	2	do.	1,190
Do.	do.	3	do.	1,175
Do.	do.	4	do.	1,130
Do.	do.	5	do.	
Sunset Coast. (*See* Opal.)				
Sunset Monarch.		1	Sec. 20, T. 31 S., R. 23 E.	
Do.		2	do.	
Do.		3	do.	
Do.		4	do.	
Twenty-Five Oil Co.		1	W. ½ sec. 25, T. 32 S., R. 23 E.	1,640
Do.		2	do.	1,655
Do.		3	do.	1,640
Do.		4	do.	1,615
Do.		5	do.	1,535
Do.		6	do.	
Do.		7	do.	
Do.		8	do.	
Do.		9	do.	
Do.		10	do.	
Do.		11	do.	
Do.		12	do.	
T. and W.		1	SE. ¼ sec. 25, T. 32 S., R. 23 E.	
Do.		2	do.	
Union.	McCloud.	1	Sec. 34, T. 31 S., R. 23 E.	
Do.	do.	2	do.	
Do.	do.	3	do.	
Do.	do.	4	do.	
Do.	Sunset Road.	1	SW. ¼ sec. 31, T. 32 S., R. 24 E.	
Do	do	2	do	
Do		1	Sec. 34, T. 32 S., R. 24 E.	
Do		2	do	
Union vs. Santa Fe		1	NW. ¼ sec. 14, T. 32 S., R. 23 E.	
Do		1	do	
Do		2	do	
Usona		1	NW. ¼ sec. 22, T. 32 S., R. 23 W.	
Western Crude.		1	NW. ¼ sec. 4, T. 32 S., R. 23 E.	
West Side.		1	NW. ¼ sec. 25, T. 32 S., R. 23 E.	
Do.		2	do.	
Do.		3	do.	
Do.		4	do.	
Wilbert.	Packard.	1	NE. ¼ sec. 22, T. 32 S., R. 23 E.	
Do.	do.	2	do.	
(?).		1	S. ½ sec. 7, T. 32 S., R. 23 E.	
(?).		2	do.	

SUNSET FIELD.

LOCATION.

The Sunset field embraces the territory along the northeastern base of the Temblor Range, south of the line marking the change from the Mount Diablo to the San Bernardino base and meridian, and includes the southeastern part of T. 12 N., R. 24 W., the northeast part of T. 11 N., R. 24 W., the southwest part of T. 12 N., R. 23 W., and the western part of T. 11 N., R. 23 W.

GEOLOGY.

OUTLINE OF STRATIGRAPHY.

The formations involved in the geology of the developed Sunset field include coarse, semiconcretionary sandstone, 400 feet or more in thickness, believed to be Vaqueros or lower Miocene in age; 2,900 feet of siliceous and clayey shale, containing numerous thin layers and connections of fine-grained calcareous material, of Monterey or lower middle Miocene age; 1,300 feet of soft light-colored diatomaceous shale, containing layers and lenses of granitic sand and conglomerate (the latter often carrying bowlders up to 2 or 3 feet in diameter), believed to be of Santa Margarita(?) age or upper middle Miocene; a great thickness of thin-bedded sands and clays and some gravels at the base with softer, thicker bedded clays and gravels above, believed to be largely upper Miocene in age, but possibly extending into the Pliocene epoch; and, finally, alluvium and stream deposits of Quaternary age. The oil is believed to have originated in the diatomaceous shales of the Monterey and Santa Margarita(?), and to have migrated either to the included porous layers of these formations or to the sands and gravels of the underlying Vaqueros or overlying McKittrick. The productive sands in the Sunset field so far tested are entirely of McKittrick age, although, as stated later (p. 213), it is the belief of the writers that commercial quantities of oil are contained in sands in the base of the Monterey or top of the Vaqueros in certain structurally favorable localities in this field.

STRUCTURE.

The Sunset field is located on the Thirty-five and California Fortune anticlines and subsidiary flexures, all of which are developed on the great folded monocline on the northeast flank of the Temblor Range. The southeastern end of the field extends into the region where the monocline bends from a southeasterly to an easterly strike. The general geology and structure of the region is shown on Plate I, while the details of the developed areas are shown on Plate IV.

OIL SANDS.

Zone B.—In mapping the underground geology of the developed territory the top of the main oil sand or zone (zone B) has been chosen for contouring, with mean sea level as the datum plane. It must be borne in mind continually, however, that the point chosen in each well does not represent the top of a continuous bed or layer, such as the term "sand" means in many of the eastern fields and occasionally in the California districts, but rather the point above the base of the McKittrick formation, where the saturation of the sandy layers or lenses with petroleum is complete enough to render their exploitation profitable. It is possible to trace certain particular layers from well to well over short distances, but it is impossible in this field to carry such a correlation for any great distance. The reason for this is obvious when one studies the oil-bearing formations in outcrop, for it is then seen that the formation consists of layers, or, more properly speaking, lenses, of gravel, sand, and clay or shale of limited extent. As in some of the other fields, the impregnated zone above the unconformity generally increases in thickness with depth, so that the horizon contoured is not parallel with the surface of unconformity, but gradually rises away from it with depth. The average rate of increase of the thickness of the zone or distance from the contoured horizon above the unconformity in the central part of the productive field is between 100 and 200 feet per mile. The variation in thickness of the oil zone is not regular, by any means, and it is not uncommon to find a comparatively deep well that contains, according to its log, a less thickness of oil sand than an adjacent shallower one. This condition is accounted for, at least in part, by the personal factor brought in by the drillers who record the logs; but in other instances it is doubtless due to thinning of porous layers, etc.

Zone B varies in thickness from 12 to 140 feet and averages about 60 feet in the northern part of the field; is 12 to 250 feet thick (this latter figure doubtless including much interbedded shale) and averages over 150 feet in the central area; and is 15 to 40 feet thick and averages nearly 20 feet in the southeastern portion. The zone consists of medium-grained to coarse sand and pebbly layers containing cobbles up to 8 inches in diameter and intercalated minor shale or clay partings. The productivity and quality of the oil on the two sides of a parting are in some places noticeably different. The oil is said to occur locally in shale. The sands are usually of quartz grains, and the pebbles and cobbles are mostly of granite, sandstone, or siliceous Miocene shale; some diabase, black quartzite, and black slate also occur as pebbles or cobbles. The sands are often more or less soft or incoherent, and as a result flow out of the wells with the oil, often making up 30 to 60 per cent of the gross yield.

Zone A.—Zone A includes the gas, tar, and oil sands intercalated in the relatively much thicker shale or clay beds lying above the more richly impregnated and commercially important sands of zone B. Zone A varies in thickness from about 250 feet in the shallower wells to as much as 500 feet (exceptional) in the deeper wells of the central portion of the field. In some of the shallower territory toward either end of the field zone A consists only of one or two thin tar sands. The individual petroliferous sands of this zone, from one to eight or possibly more in any particular well, are 5 to 35 feet thick, and vary in composition from medium to coarse grained and pebbly quartz sand; cobbles occur more rarely than in zone B. The gas and tar sands are usually found in the upper portion of the zone, while some of the lower sands or sandy shales carry minor and possibly even commercial quantities of oil. In some of the wells in the central part of this field good showings of 16° and 18° Baumé oil are said to have been encountered in the lower part of zone A. Water sands are also associated with the petroliferous sands in zone A, especially in the portions of the field overlying synclines. The lowest oil or tar-bearing sands in zone A are usually separated from zone B by 20 to 60 feet of stiff blue clay, an ideal landing place for casing.

Beds above zone A.—The beds above zone A consist of shale and clay with minor amounts of sand and gravel, the latter usually occurring near the surface and being of stream origin. The sands of this part of the formation often carry water, and very rarely a little tar or gas.

Beds below zone B.—The beds below zone B consist almost entirely of blue and brown shale with occasional sand layers or lenses, which sometimes carry water. This shale is a part of the Miocene shale formations (Santa Margarita (?) and Monterey) exposed in the hills southwest of the developed territory, and occurs in an unconformable position below the McKittrick formation, in the base of which is zone B. The Miocene shale formation is several thousand feet thick, and as the wells in this developed territory penetrate the upper beds only, it is almost certain that they would never be able to drill through it into the underlying sands of the Vaqueros (lower Miocene) in the present developed part of the field.

WATER SANDS.

Water occurs at one place or another throughout practically the whole thickness of strata in this field so far penetrated by the drill. It is nearly always present in the sands above zone A, although in some of the wells in the northern part of the field it is either lacking or present only in small quantities. The first water is encountered at a depth of 80 to 450 feet, depending on location, the deepest occurrences generally being in the synclines. Water is particularly

abundant in the areas overlying synclines, such as the northern part of sec. 2, T. 23 N., R. 12 W., and the syncline near Hazelton, where the strike bends from southeast to east. In this latter area zone A contains considerable quantities of water, usually charged with sulphur. The water in the beds above zone B is highly mineralized, and consequently often useless. It sometimes flows, but more often rises only a short distance in the holes. The greatest flow of water yet encountered in the field comes from Northern No. 1, from a sand that either just overlies or is a part of zone B. This water is warm and flows from the well under a considerable pressure, probably due to gas. It is utilized for development purposes by some of the companies. Water is reported immediately under zone B in most of the wells that pass entirely through the oil zone. It is believed that this condition prevails throughout much of the field. Deep wells penetrating the Miocene shale below zone B generally strike artesian flows of warm, more or less mineralized, water in the intercalated sands. Some of these wells reach a depth of 1,700 feet and yield over 3,000 barrels per day. In one well the water comes out with a temperature of 120° F. Water from these deep wells, after passing through a salt precipitating process, forms a part of the domestic supply for the field.

PRODUCT.

The hydrocarbon products of the Sunset field consist of heavy tar, oil varying in gravity from 11° to about 20° Baumé, and gas. The tar occurs in springs along the outcrops of the oil sands, in certain exposures of the upturned petroliferous siliceous shales in the southeastern part of the field, and in certain layers or lenses encountered in the wells in zone A.

The oil is black and the heavier qualities very viscous. The heavier oil, averaging from 12° to 13° Baumé, occurs in zone B in the shallower wells which are located at either end and along the southwestern edge of the field. The lighter oil, 13.5° to 20° Baumé, is produced by the deeper wells, especially those in the northern part of the field. The lightest oil occurs in the deeper wells at the northern end of the field. Oil said to test 16° to 18° Baumé occurs in moderate amounts in a series of shales and fine sands in the base of zone A, but none so far is utilized in any of the wells.

Gas of a good quality occurs under great pressure with the oil in zone B, and also in minor amounts in some of the sands of zone A. Owing to the peculiar manipulation of the wells it is more or less difficult to save the gas, and much of it is wasted.

As indicating the great pressure under which the gas is confined in the deeper wells, it is stated that in the central part of the field a string of tools became stuck in a 9⅝ inch casing in a well 880 feet deep,

and the gas pressure at the bottom was great enough to force tools and casing upward in the well until the casing was chained down to the derrick floor. Assuming 22 pounds per foot for the weight of the casing, 3,000 pounds for the weights of the tools, the total weight raised by the gas was over 22,000 pounds, not including the friction between the casing and walls of the well overcome in the operation, which must have been considerable. The pressure was probably between 500 and 800 pounds per square inch.

PRODUCTION.

The wells vary in production from 4 to 25 barrels per day for the shallower holes yielding heavy oil to over 400 barrels per day for the deeper ones producing a better grade. The average daily production for the wells in the northwest portion of the field is 25 to 40 barrels; in the central and northern areas 75 to 400 barrels, and in the southeastern synclinal portion 50 to 100 barrels. Contrary to the rule in most fields, some of the wells in this one increase their production after operation for awhile, this condition resulting from a gradual loosening up of the oil sand, which packs around the casing, by intermittent agitation of the casing. Those wells which start with a heavy production (said to have been at the rate of 3,000 barrels per day for a short while in at least one of the wells) usually fall off rapidly during the first few days of their operation, but still have been known to maintain a yield of 200 to 300 barrels for a period of two or three years at least. Much sand accompanies the oil, sometimes as much as two-thirds of the gross yield of the well being sand. One well alone produced over 110,000 cubic feet of sand in about four years and another has yielded almost as much in two years. The yield of sand gradually decreases with the age of the well, but at no time entirely ceases. The production of sand is less toward the southeast and north, some wells in these parts of the field yielding only moderate amounts with the oil.

METHODS.

Depth of wells.—The wells in the Sunset field vary from 350 to over 1,900 feet in depth.

Drilling.—The method of drilling in this field is similar to that generally in use in the other California fields, the standard rig being used. An innovation in the method of facilitating drilling through the troublesome cobble beds was the use of dynamite to break up the bowlders in the Ruby wells. It is said that the experiment was highly successful.

Shutting off water.—The water above zone A in the wells is usually shut off with the first string of casing in the clay or shale beds just

above the top of zone A, or occasionally in its upper portion. The second string is generally landed in the clay between zones A and B, although it is not unusual to carry the second string into the oil sand. No method has so far been devised to successfully shut off the big flow of water encountered at the top of zone B in the wells in the northeast corner of sec. 12 and the southeast corner of sec. 1, T. 11 N., R. 24 W.

Operation of the wells.—The peculiar conditions—soft sand accompanying the flowing oil in great quantities, heavy oil, and strong gas pressure—make the problem of well operation in this field a serious one. A method of handling the wells which has proved highly successful was discovered several years ago by accident and is said to have been first used in Sunset Monarch well No. 3. This method consists in intermittently agitating the sand within or below the casing which penetrates the oil sand by means of a smaller "agitating string" (usually a 7⅝-inch string within a 9⅝-inch casing). If the sand is thus kept loosened by agitation, the gas pressure is strong enough to cause the well to flow. When the gas pressure weakens compressed air is forced down the agitating string, usually with successful results. It has been found impracticable for various reasons to pump oil containing so much sand, and the agitation method has therefore been the salvation of the field.

Separation of oil and sand.—As has been mentioned at many places throughout this report, the oil in the Sunset field is accompanied by large quantities of sand. To separate the oil and sand large earthen reservoirs are built around each well, and the floor of the derrick erected from 8 to 12 feet above the bottom of the reservoir. The oil and sand are run into the reservoir through a pipe or open trough which can be directed to any part of the basin, and the product is allowed to flow out and stand. The sand collects in cones under the discharge pipe, while the oil settles to the lower part of the basin and is conducted away to storage tanks or reservoirs. Much of the oil is so heavy and viscous that artificial heat often has to be applied to it for facility in handling, especially in cold weather.

LOCAL AREAS OF SUNSET FIELD.

CALIFORNIA FORTUNE—J. B. & B.—SUNSET MONARCH AREA.

Location.—The area denoted by the heading includes wells in the southeast corner of sec. 28, the northeast corner of sec. 33, the southwest corner of sec. 27, all of secs. 34, 35, and 36, T. 12 N., R. 24 W., and a small area in the northern part of the NW. ¼ sec. 2, T. 11 N., R. 24 W. Among the principal properties lying within the area are the Union, California Fortune, Acme, and Sunset Monarch. The wells are situated on the northeast flank of the California Fortune

anticline, on the Thirty-five anticline, and on the subsidiary wrinkles between these two.

Zone B.—Zone B varies in thickness from 25 to 140 feet, and averages probably about 60 feet. The zone is reported in most of the areas as a continuous sand, although in a few a shale or clay parting a few feet in thickness sets off a portion of the sand at the top or bottom, the isolated portion usually carrying oil either lighter or heavier than the main body of the sand. A typical section of zone B from a well in the NW. ¼ sec. 34 is as follows:

Typical section of zone B in well in the NW. ¼ sec. 34, T. 12 N., R. 24 W.

	Feet.
Coarse sand	25
Cobbles	4
Medium-grained sand	10
Cobbles	4
	43

The sand is usually coarse granitic in texture, with grains often approaching the size of wheat. The conglomeratic layers often carry cobbles up to 8 inches in diameter; these are mostly quartz and granite, but black slate and considerable quantities of siliceous shale are also found in the coarse beds.

Zone A.—Zone A extends 260 feet or less above zone B in the area of the southeast corner of sec. 34; northwest of that point zone A is not a well-developed feature, many of the well logs indicating no tar or oil sands above zone B, and it is possible that the California Fortune and adjacent wells may be obtaining their oil from beds the equivalent of zone A farther southeast. This is a point that will be settled only after exploitation of the territory in the center of sec. 34. The contours are drawn with the assumption that the productive sands are zone B, the basal beds of the McKittrick formation, which seems the most plausible hypothesis. Zone A consists of one or more sands, 5 to 10 feet through, carrying gas, tar, or a little oil, interbedded in much greater thicknesses of shale or clay. Some of the sands are dry or carry only traces of hydrocarbons. A little water-carrying sand is sometimes interbedded in the upper part of the zone in the Phœnix syncline.

Beds above zone A.—The beds above zone A consist largely of blue clay and shale, in which occur minor sands, water sands, shells, and layers of cobbles, the latter believed to be stream wash where they occur near the surface.

Water sands.—The water sands in the area are unimportant except in the region of the Phœnix syncline, where one and sometimes two or three occur above the lowest tar sands. A water sand 5 to 10 feet through usually overlies zone A, but is not encountered in a considerable number of the wells.

Product.—The oil in this area is black and heavy, varying in gravity between 11.5° and 15° Baumé, averaging about 13.5°. Much gas accompanies the oil, and gas is also encountered in zone A above the productive beds.

Production.—The initial individual production of the wells, especially of those first drilled in any particular piece of territory, has been known to reach from 400 to 600 barrels per day for a short time. The average production after operating is probably not over 25 to 40 barrels for the whole area. Much gas and sand accompany the oil, the latter sometimes being in excess of the oil, especially during the early part of any well's operation. In so far as they have been tested the wells hold to a fairly constant output after the initial decline.

Methods.—The productive wells of the area are from about 500 to 925 feet deep. Some of them flow without perforation from the casing stopping in the oil sand, but most of the wells are perforated and pump. Water is usually shut off below zone A (tar sands) where plenty of good shale or clay is available for landing casing.

Typical logs.—A log typical of the wells in the northwestern section of the area is as follows:

Log of well in the NW. ¼ sec. 34, T. 12 N., R. 24 W.

	Feet.
Soil	6
Sand	45
Hardpan	56
Cement sandstone	80
Blue clay	90
Blue sandstone and clay	105
Blue clay	136
Blue clay	174
Blue shale	200
Hard shell	202
Blue shale	231
Shale or clay	281
Sand	286
Gritty blue shale	315
Soft, sandy blue shale	365
Blue clay	379
Blue shale	400
Blue clay	417
Soft sandstone and blue shale	438
Blue shale	455
Soft sandy blue shale	477
Blue shale	483
Brown shale	489
Blue shale	506
Oil sand	516
Hard shell	518
Oil sand	531
Hard shell	534

	Feet.
Oil sand	537
Hard shell	538
Oil sand	560
Cobbles and oil sand	563
Oil sand	588
Oil sand and cobbles	589
Oil sand	610
Oil sand and cobbles	611
Oil sand	660. 5
Oil sand and cobbles	664
Oil sand and brown shale	672
Oil sand	691
Oil sand and brown shale	697

Two logs typical of wells in the southwestern section of the area follow:

Log of well in SE. ¼ sec. 34, T. 12 N., R. 24 W.

	Feet.
Yellow sandy clay	130
Blue clay	142
Purple sand rock	152
Blue sandy clay	197
Blue sand	218
Sticky blue clay	250
Hard sandstone	270
Blue clay	300
Blue clay, sandy	365
Tar sand, not much oil, very fine	370
Blue clay	395
Blue joint clay	415
Oil sand, not much gas	430
Hard shell	431
Brown shale, gas with oil	442
Blue and brown shale, very cavy	500
Blue joint clay or shale	550
Oil sand, much gas	586
Landed on shell	585

Log of well in NW. ¼ sec. 2, T. 11 N., R. 24 W.

	Feet.
Wash and sand	90
Blue shale and sand (water at 376)	376
Blue shale	412
Blue clay	432
Tar sand and blue shale	536
Blue clay	566
Blue shale	593
Brown shale and sand with oil	617
Oil sand	634
Brown shale	638
Oil sand	740
Oil sand and shale	756

ARCOLA—OCCIDENTAL—BARRETT AREA.

Location.—This area includes the wells in sec. 2, T. 11 N., R. 24 W., with the exception of those in the extreme northern and eastern portions of the section. Among the wells described are those formerly known as the Santa Rosa and Occidental (now belonging to the Sunset Monarch), the Arcola, and the Barrett wells in the center of the SE. ¼ sec. 2, belonging to the Union. The wells are on the northeastern flank of the California Fortune anticline, on the Sunset Monarch anticline, and in the syncline between the two anticlines. The Sunset Monarch anticline is local in extent and has been located principally upon evidence furnished by well logs. Its exact relations and character are unknown, and a fault may possibly be associated with it.

Zone B.—Zone B is from 20 to 140 feet thick, the second figure undoubtedly including considerable intercalated shale. The sand is of quartz grains and coarse for the most part, and some of it contains pebbles of granite, blue shale, quartz, and siliceous shale exhibiting impressions of ostracods. It is usually incoherent and much of it accompanies the oil, especially immediately following the inception of the wells. Zone B is overlain by sandy shale and shell, and overlies the brown shale which occupies the hills west of Sunset. Water is indicated as occurring at the base of zone B in only one log in this area, and that is the log of a well near the axis of the Sunset Monarch anticline, in a region where the strata are probably much disturbed.

Zone A.—Zone A is usually less than 200 feet thick, although near the center of sec. 2 some oil and tar sands are encountered as much as 370 feet above the top of zone B. Zone A contains from one to three petroliferous sands from 5 to 23 feet thick, interbedded with clay and numerous hard shell layers. Heavy oil or tar and considerable gas is usually found in the sands of this zone; in one well near the center of sec. 2 the uppermost sand (here 8 feet thick) of zone A yielded oil in great enough quantity and under pressure sufficient to cause it to flow over the casing a short while. This sand was never thoroughly tested, however.

Beds below zone B.—The beds below zone B, which, from surface evidence, are believed to lie unconformably with it, consist almost entirely of blue and brown shale with occasional lenses of sand. Many of these intercalated sands carry water and some of them gas. The steep angle at which the strata of this underlying shale rest lessens the probability of reaching the oil sands which lie at the base of the Monterey shale in wells of reasonable depth.

Beds above zone A.—The strata overlying zone A consist largely of blue clay and shale, with some sand, water sand, and cobble and

shell layers, as in the other areas in this field. The cobble beds are mostly encountered near the surface and many of them probably represent surface wash.

Water sands.—Water occurs in sands, usually just above zone A or under the first tar sand, at 140 to 400 feet below the surface. They are from 5 to 15 feet in thickness, more often the former, and are usually coarse-grained. In no well were more than two water sands reported as occurring above zone A. Water does not occur immediately under zone B in any of the wells tested. The waters in the beds overlying zone B are all of a very poor quality, being highly mineralized.

Two wells within this area have penetrated to considerable depths below zone B, and each secured a supply of fairly good water. In the well in the southeast part of the NE. ¼ sec. 2 water occurs at about 500 and 1,000 feet below the surface, at the latter horizon in considerable quantities. The well in the northern part of the SW. ¼ sec. 2 taps water sands at about 500 feet and also at 1,500 feet, the latter zone consisting of several sands yielding about 3,000 barrels per day of sulphur water, which comes from the well under artesian head at a temperature said to be 120° F.

Product.—The wells of this area yield black oil varying in gravity from 13° to 16° Baumé, with an average of between 14° and 15°. The only regularity noted in the variation is that the thicker and coarser sands yield the heavier oil. It is said that the oil occurring in the sands of zone A is usually lighter than that found in zone B, although none of these upper sands are utilized. Much gas accompanies the oil, as in the other areas of this field.

Production.—The individual production varies from 10 to 100 barrels per day, averaging about 40 barrels, the deeper wells on the southwest side of the Sunset Monarch flexure being the more productive. Sand in large quantities usually accompanies the oil. The wells near the axis of the Sunset Monarch anticline or flexure are either nonproductive or the least productive in the area.

Methods.—The depth of the wells passing only through the productive sands (zone B) varies from 350 to 940 feet; some water wells passing through the oil sands and down into the underlying shale formations attain a depth of 1,500 to 1,700 feet. The wells flow as long as the gas pressure is sufficient to force out the oil and sand; most wells, however, soon lose their pressure and must be pumped. Sand interferes with the pumping and makes operation expensive. The water is usually shut off between zones A and B, but occasionally above zone A; 11⅝-inch or 9⅝-inch casing is usually the largest used.

Typical logs.—A log typical of the wells in the central part of the area is the following:

Log of well near the southwest corner of the NE. ¼ sec. 2, T. 11 N., R. 24 W.

	Feet.
Surface	80
Blue clay and sand	120
Sand rock	128
Clay and sand	260
Sand rock	275
Hard clay	295
Gas sand	300
Oil sand	308
Water sand	311
Blue clay	340
Brown sand, with water	358
Greasy shell	368
Water sand	376
Blue clay	393
Blue clay and slate	433
Blue clay	441
Fluffy sand	448
Blue shale	500
Brown shale	660
Oil sand	708

A log typical of the wells in the northwestern portion of the area is as follows:

Log of well near the center of the NW. ¼ sec. 2, T. 11 N., R. 24 W.

	Feet.
Surface yellow clay and slate	180
Blue clay	195
Yellow sand	205
Blue clay, very cavy	230
Sand and shale	350
Blue shale	270
Hard shell and sand	278
Blue clay	305
Hard shell	308
Blue shale	324
Sandy shale	336
Hard shell	348
Blue shale	360
Shell	362
Blue clay	375
Lime rock	377
Blue shale, with hard shell and sulphur	398
Blue sand, with water	403
Blue clay (cavy)	412
Very hard shell	415
Blue clay	430
Brown shale and oil sand	440
Blue shale and oil sand	465
Blue shale	551
Soft shell	556
Oil sand	576
Brown shale	620

McCUTCHEON–MONTE CRISTO–RUBY AREA.

Location.—This area comprises the eastern part of the NE. ¼ sec. 2 and the NW. ¼ sec. 1, T. 11 N., R. 24 W., and includes the wells of the Sunset Rex, McCutcheon, United Crude, Transport (now Sunset Monarch), Monte Cristo, and Ruby oil companies. The wells occupy the flanks of the Phœnix syncline, which plunges in a southeasterly direction through the middle of the north line of sec. 2 and the flanks of the Thirty-five anticline.

Zone B.—The productive strata included in zone B vary in total thickness from 40 to 135 feet, the greater thickness usually occurring in the deeper wells. The individual sands of zone B become thinner and more numerous toward the east down the dip, the productive zone thickening by the intercalation of brown shale. A typical section of zone B shows five or six alternations of brown shale and oil sand beds, the latter often carrying cobbles of considerable size. The sand is largely granitic, coarse, and more or less incoherent, and flows out with the oil, although in less quantities than from the wells farther south. The cobbles occur toward the top of the zone in the southern wells, and an unusual amount of gas seems to be associated with the oil in the cobble-bearing strata. The oil is said to occur often in shale in the deeper wells, and this product is said to resemble mud. In the northern part of the area the richest sand occurs near the top of zone B.

Zone A.—Zone A usually embraces the strata for about 800 feet above the top of zone B, and even a little higher in some of the deeper wells. The beds carrying tar are more in evidence in the southern or shallower wells, water appearing to supplant the tar in certain of the beds toward the north end. The sands are usually 8 to 20 feet thick and occupy only a small percentage of the section included within the limits of the zone. Some of the sands of zone A, especially the lower ones, show indications of oil in commercial quantities, but none have been adequately tested so far as the writers are aware. Zone A and zone B are usually separated by 40 to 250 feet of blue clay or shale. This great variation in the thickness of nonpetroliferous beds between the two zones is conclusive evidence of the extreme localization of deposition in this general region.

Beds above zone A.—The beds above zone A consist of blue clay with minor amounts of intercalated sand and water sand. The sand increases in importance toward the northwest, but even in those logs showing the most sand the shale still predominates. Cobbles are reported in the upper beds in only two or three wells, and these in the northern part of the area.

Water sands.—The first water sand is struck at depths ranging from 130 feet below the surface in the shallower wells to over 500

feet deep in the deeper ones. The water sands occur as far down as within 40 feet of the top of zone A, and in some instances they are even found below the uppermost tar sand. An unusually big flow of water is reported in sands just above zone A in a well in the E. ½ NE. ¼ sec. 2. The water sands are from 5 to 28 feet in thickness, and occur as lenses rather than as beds having a wide extent. Water is reported in a bed just below what is believed to be zone B (the productive zone) in one of the deep wells near the center of the E. ½ NE. ¼ sec. 2. This occurrence is very significant as indicating the danger of too deep drilling in this particular part of the field.

Product.—The oil produced in this area is black and varies from 13° to 20° Baumé in gravity, the lighter oil occurring in the deeper wells in the eastern part of the area. Much gas accompanies the oil, as in other parts of the field.

Production.—Some of the wells in the area having a high initial production drop rapidly after a few hours or days, while others with a low initial output increase it with age. One of the deeper wells is said to have flowed for a few hours at the rate of 2,000 barrels per day, but soon dropped to a daily run of 500 barrels and then to 200 barrels, which it still holds when in good condition. Another well at the eastern end of the area started with a production of 3,000 barrels per day, but at the end of ten days had dropped to a flow of 600 barrels. Wells in the western part of the area having an initial daily production of 35 to 50 barrels produced from 75 to 90 barrels after a few weeks. The oil sand penetrated by these wells appeared to be dry during the course of the drilling. The average individual initial production for wells in this area is between 350 and 500 barrels per day; the average daily production is probably 150 barrels per well.

Methods.—The wells in this area vary in depth from about 700 to over 1,400 feet. They are operated in the same manner as those farther south—that is, by agitation of the inner tubing, the oil flowing out between the inner and outer strings of casing, and by pumping. In some of the wells it takes some little time to "liven up" the oil sand and start it flowing. Dynamite has been used successfully in some of the wells in this area to shatter the cobbles and bowlders encountered in drilling. This use of explosives is not to be compared with its use in the fields of the Eastern States, where the rocks containing the oil are blasted to increase the flow of the oil.

Typical logs.—A typical log of one of the shallower wells in this area is as follows:

Log of well in the southern part of the NE. ¼ sec. 2, T. 11 N., R. 24 W.

	Feet.
Surface	55
Gypsum	137
Blue sandy clay	332
Dry sand	340

	Feet.
Blue clay, water	387
Blue clay and shells	430
Oil sand	438
Blue clay	474
Dry sand	476
Blue clay	484
Hard shell	487
Blue clay	500
Hard shell	502
Blue clay	507
Hard shell	508
Brown and blue clay	525
Shell	526
Oil sand	538
Blue clay	546
Oil sand	555
Blue clay	608
Hard shell	609
Blue clay	614
Oil sand	616
Blue clay	633
Shell	635
Blue clay	678
Oil sand	790

A typical log of one of the deeper wells of the area is as follows:

Log of well in the northern part of the NE. ¼ sec. 2, T. 11 N., R. 24 W.

	Feet.
Yellow earth	85
Yellow clay	100
Cement gravel	150
Blue shale, clay, and shells	495
Sand	510
Water sand	515
Hard shell	525
Blue clay	560
Sand	570
Blue clay	610
Sand	615
Blue mud	650
Sand	660
Blue mud	680
Clay	795
Sand with oil and gas	805
Blue clay and shell	850
Sand	855
Blue clay and shale	880
Brown shale	905
Tar sand and shale	910
Blue shale	1,017
Brown shale, rotten	1,185
Oil sand	1,220
Brown shale	1,227
Oil sand	1,233

ADELINE-GATE CITY-FULTON AREA.

Location.—This area includes the eastern part of the SE. ¼ sec. 2 and the western part of the SW. ¼ sec. 1, T. 11 N., R. 24 W., and comprises property operated under the following companies: Adeline, Gate City, Fulton, and Maricopa (now belongs to Gate City). Most of the wells are on the flanks of a small dome or quaquaversal which is developed on the side of the California Fortune anticline.

Zone B.—Zone B is believed to be about 40 to 100 feet thick in this area, although thicknesses of 262 and 271 feet are noted for it in the logs of two widely separated wells. It is believed that these last thicknesses include large amounts of intercalated shale, and that the first figures should be taken as representing the range of thickness in the wells. The following section of the productive zone is believed to be characteristic of zone B:

Section characteristic of zone B, Adeline-Gate City-Fulton area.

	Feet.
Overlying beds	715
Shale with gas	745
Oil sand	755
Shale	777
Oil sand (good)	780
Shale	790
Oil sand (very rich)	800
Shale	810
Oil sand (good)	815
Shale	816

The sand varies from fine-grained to coarse or pebbly, and carries some cobbles of considerable size. The sand consists of quartz, black slate, limestone, and siliceous shale grains, with pebbles of all these and also of granite. The oil zone is in some places divided into two parts by a hard shell, and in these wells the productivity of the portion below the shell is usually greater than that above. The thinner sands in zone B become dry in the shallower wells.

Zone A.—Zone A is usually between 240 and 300 feet thick, though in the deeper holes it extends as high as 540 feet above the top of zone B. The zone consists of alternating moderately thin beds of clay or shale and medium to coarse grained sand, the latter usually, and the shale rarely, carrying gas. Heavy oil or tar, or moderate amounts of oil, the latter mostly in the lower sands, occur in the zone. Water occurs rarely in zone A except in the shallower wells, where tar and water (the latter probably surface water) are reported closely associated. One of the wells in the western part of the SW. ¼ sec. 1 showed a thin stratum of sand in zone A carrying a little water thoroughly charged with sulphur. In one or two other wells where zone A is exceptionally thick a water sand occurs below the uppermost tar sands. No water whatever occurs in the lower or even the middle

part of the zone. The lowest oil or tar sand in zone A is usually separated from zone B by about 40 to 60 feet of clay or shale, although in some wells, especially the shallower ones, tar sand or dry oil sand is reported as immediately overlying the productive zone.

Beds above zone A.—The strata above zone A consist largely of blue clay with occasional sand, water, and shell layers, and some gravel beds near the surface. Traces of tar and some gas are reported rarely in the upper beds, and seem to represent isolated lenses of hydrocarbon-bearing sands.

Water sands.—The first water is encountered in the shallow and moderately deep wells at 80 to 180 feet below the surface; in the deeper wells at 250 to 350 feet. No water is reported in the wells near the center of the NE. ¼ SE. ¼ sec. 2. The lowest water sand in the beds above zone A is usually separated from zone A by 40 to 60 feet of clay, although in many of the wells no water is reported below the first water sand, which may be several hunderd feet above zone A. Sulphur water is reported as occurring below the top of zone A in one well, and in one or two others water sands in zone A are mentioned in the logs; these occurrences are believed to represent isolated lenses of water sand. Only one deep well has been put down in this area, and that penetrates about 1,100 feet of blue shale, with occasional thin sands and shells below zone B before reaching important water sands. The water sands are overlain by 50 feet of hard sand shell. This well is about 1,700 feet deep, and its initial production of water was about 800 barrels per day.

Product.—Heavy tar or asphaltum occurs in the shallower wells (not operating) in this area; oil of 11.5° Baumé gravity in the moderately shallow ones and oil up to 13.25° in the deeper ones; the average for the area is probably about 12.5°. The oil carries considerable gas, and for this reason drops slightly in gravity upon standing.

Production.—The wells vary in initial production from 25 to over 800 barrels per day, the latter being very unusual. Most of the wells drop to a daily average of 75 to 200 barrels, flowing under their own gas pressure, and this is sometimes raised to over 250 barrels by the use of compressed air. Much sand accompanies the oil from the wells, as high as 50 to 70 per cent of the product during the early life of the well being sand. According to the estimates of the writers, based on the sand in the sump reservoir, Adeline well No. 13 has produced over 110,000 cubic feet of sand since it began flowing in February; 1904. Large quantities of gas are produced by the wells in this area, but the peculiar way of operating the wells precludes the profitable saving of much of the gas.

Methods.—The productive wells in this area are from 400 to 1,060 feet deep. One water well which passes into the shale formation

underlying zone B attains a depth of about 1,700 feet. The wells are kept flowing by agitating the sand with the inner casing. Some of the wells are also operated by means of compressed air, which materially augments the production under normal gas pressure.

Typical logs.—The following is a typical log of a well in the western or shallow part of the area:

Log of well in the north-central part of the SE. ¼ sec. 2, T. 11 N., R. 24 W.

	Feet.
Surface	120
Blue clay	275
Tar sand (no oil)	295
Blue clay	296
Shell	301
Tar sand (no oil)	347
Shell	348
Blue clay	353
Shell	354
Blue clay	365
Brown shale	372
Gravelly tar sand (water)	380
Blue clay	391
Gravelly oil sand	410
Blue clay	413
Brown shale	420
Blue clay	424
Brown shale	448
Blue clay	480
Brown shale	490
Blue clay	506
Brown shale	509
Blue clay	548
Coarse sand and gas	558
Granite bowlders and gas and oil	564
Coarse gravel and sand	580

A typical log of the wells in the deeper territory is as follows:

Log of well near the center of the SW. ¼ sec. 1, T. 11 N., R. 24 W.

	Feet.
Surface	323
Water sand	325
Shale and clay	368
Shell	373
Clay	375
Water sand	390
Clay	405
Shale and clay	470
Shale	475
Clay	480
Shell	485
Clay	535
Shale	552
Oil sand, tar sand, gas, and oil	561

	Feet.
Shale	580
Clay	582
Shale	615
Clay	625
Oil sand, oil, and gas	635
Shale and shells	655
Shale	658
Heaving sand and much gas	668
Oil sand	685
Clay and shells	700
Shale	720
Oil sand	722
Shale	752
Oil sand	760
Shale	772
Hard shell	775
Oil sand, most of gas found here	795
Oil-bearing shale	883
Shale and oil sand	904
Oil sand (coarse)	1,067

FULTON—SNOOK—LADY WASHINGTON AREA.

Locations.—This area comprises the SE. ¼ and the eastern part of the SW. ¼ sec. 1, the northern part of sec. 12, T. 11 N., R. 24 W., the northern part of sec. 7, and the southwestern part of sec. 6, T. 11 N., R. 23 W. The wells are operated by the following oil companies, among others: Fulton, Kern Sunset, New Center, and Walter Snook.

Zone B.—Zone B varies from 12 feet thick in the shallower wells to 140 feet thick in the deeper. This zone is represented as a continuous oil sand in all the logs examined, but it is believed to consist of alternating sand and clay beds, the former largely predominating. The sand is generally incoherent and consists mostly of medium to coarse quartz grains, and in many places carries pebbles and cobbles of granite, basalt, and siliceous shale. Fragments of the oil sand containing fossil seashells are sometimes brought up in the bailers. A hard shell usually caps zone B, although a clay layer is reported in some of the logs.

A well in the southeastern part of sec. 1, T. 11 N., R. 24 W., penetrates nearly 300 feet of sand showing traces of oil, just below the sand carrying the heavy water flow of this particular locality. It is believed that this sand is the equivalent of zone B in the wells to the southwest. Owing to the thin and soft nature of the brown shale overlying this oil sand and separating it from the sand carrying the heavy flow of water it seems improbable that it will be possible to save the oil which it may contain.

Zone A.—The zone of oil, tar, and gas sands usually begins about 260 feet above the top of zone B; the lowest petroliferous layer in zone A is generally separated from the top of zone B by 60

to 80 feet of brown or blue clay or shale. The number of individual petroliferous sands or sand lenses in zone A is from two to seven in different wells. These are separated by layers of clay, shell, or shale much thicker in the aggregate than the sand beds. The individual sands are from 3 to 33 feet thick in the wells and vary in grain from fine to coarse sand and gravel, carrying cobbles up to 8 inches or more in diameter. Some of the sands are dry; others contain a heavy tar; and some, notably those in the lower part of the zone, carry oil in considerable quantities. Nearly all the sands contain more or less gas. A series of alternating sand and shale layers, 36 feet thick, the top of which was 110 feet above the top of zone B, is said to have yielded enough 18° Baumé gravity oil where the sand was first penetrated to flow over the top of the casing for a short time. This sand was never thoroughly tested, but the occurrence indicates the possibility of obtaining commercial quantities of oil in other sands besides those of the main oil zone, zone B. Water occurs in zone A about 180 feet above the top of zone B in the wells near the middle of the west line of the NE. ¼ sec. 12, but is not encountered in the same zone in any of the other wells of the area whose logs were examined by the writers.

Beds above zone A.—The beds above zone A consist largely of blue clay and fine-grained sandstone in thin alternating beds and zones and minor amounts of coarse gravel and conglomerate, the former usually at or near the surface. Water occurs in some of the sands and occasionally traces of gas or oil are found in them.

Water sands.—In addition to the first water sands, which occur between the surface and 250 feet, there are usually two or three other sands carrying water in the formation above zone A. In one well at the south end of the area the first water is reported at 560 feet. The lowest water sand is in some places separated from zone A by only 20 feet of blue clay, and it is usually in this clay that the upper waters are shut off. The water sands vary from fine-grained to conglomeratic and range from 2 or 3 feet up to 10 feet in thickness. The water is highly mineralized and useless for most purposes.

One of the most remarkable flows of water ever encountered in an oil field in California was that struck by Northern No. 1. At about the point where zone B (the productive sand) was expected in this well the drill went through a hard shell into a dry oil sand, but got no farther, as at this point a heavy flow of water—estimated at from 20,000 to 50,000 barrels per day—came into the hole. This flow diminished somewhat, but at the present time (November, 1909) is very strong. The same water is encountered at the same horizon in a near-by well, which, upon passing through the water sand and a

thin underlying brown shale layer, entered about 300 feet of oil sand, supposed to be zone B. It is the belief of the writers that this water comes from a more or less local lens of sand immediately overlying zone B, and that it derives its pressure from gas which has access to the lens from some of the adjacent petroliferous layers. It is inconceivable that the water is under an artesian head, because it is not encountered in any of the wells penetrating the same zone farther southeast and higher up on the dip. The great amount of gas accompanying the water is also strong evidence of the source of the uncommon pressure. It is also the belief of the writers that the flow will gradually decrease as the gas pressure is relieved, as would be expected in a sealed reservoir, and that in time it will entirely cease. The underground conditions causing this flow are a menace to the oil possibilities only of that territory which is underlain by the particular sand lens carrying the water. At present the southwestern limit of the lens is marked by a line running in a north-northwesterly direction between Northern wells Nos. 1 and 4. The extent of the lens toward the north, east, and south is problematical, although from some evidence the writers are led to believe that the unfavorable conditions extend northeastward for at least one-half mile from the southwestern limit of the lens.

Product.—The wells yield oil and sand, the latter sometimes making up nearly half the product. The oil is black and varies in gravity from 12° to 15° Baumé. Oil of 16° and 18° Baumé gravity is said to come from the shale and possibly certain sands toward the base of zone A. Much gas occurs with the oil and some of this is saved on most of the properties.

Production.—The production of the wells in this area varies from a mere trace, reported in one of the wells in the southwestern part, to an initial production of 800 barrels per day for one of the deeper holes. The average daily production after the initial head has blown off is between 100 and 250 barrels per well. The wells fall off materially in production with reduction of the gas pressure, but this deficiency is now being supplied on some of the properties by the installation of air compressors, which are used instead of pumps.

Methods.—The wells in this area are from 800 to over 1,200 feet deep. The water is shut off in the clay between the lowest water sand and the uppermost tar sand in zone A, that is, about 250 feet above the top of zone B. The second string of casing is usually landed in the clay above zone B. Clay rather than shell is utilized in this field for landing the casing, and is found very satisfactory as a general rule. The wells are operated, as in other parts of the field, by agitating the sand with the inner string of casing.

Typical log.—A typical log of the wells of this area is as follows:

Log of well near center of north line of sec. 12, T. 11 N., R. 24 W.

	Feet.
Surface	178
Blue clay	205
Water sand	206
Blue clay	220
Yellow clay and gravel	335
Blue clay	363
Hard shell	368
Blue clay	394
Shell	396
Blue clay	405
Shell	408
Blue clay	416
Clay and sand	468
Shell	469
Clay and sand	495
Shell	497
Water and sand	500
Blue shale	568
Shell	571
Blue clay	581
Sand, clay, and shell	590
Blue clay	593
Shell	624
Blue clay	638
Shell	640
Clay and sand	655
Blue clay	670
Water sand	675
Shell	677
Blue clay	685
Sand	690
Blue clay	696
Shell	700
Blue clay	760
Sand and clay (water)	785
Shell	788
Hard sand	796
Water	798
Shell	799
Blue clay	807
Tar sand	840
Blue clay	859
Shell	863
Oil sand	869
Shell	872
Blue clay	880
Oil sand	890
Blue clay	900
Shell	901
Oil sand	905

	Feet.
Shell	908
Blue clay	912
Shell	913
Gravelly clay	949
Oil sand	965
Good oil sand	980
Blue clay	985
Oil sand	990
Blue clay	1,002
Shell	1,003
Shale and gas	1,036
Shell	1,037
Gray shale	1,062
Blue clay	1,068
Hard shell	1,072
Blue shale	1,080
Shell	1,087
Oil sand	1,227

GOLDEN WEST—TOPAZ—NAVAJO AREA.

Location.—This area embraces the developed territory between the Golden West lease on the northwest (in the SE. ¼ sec. 12, T. 11 N., R. 24 W.) and the Navajo wells (in the NW. ¼ sec. 20, T. 11 N., R. 23 W.), and includes property operated by the Golden West, Lion, Topaz, Sunset Monarch (formerly American Girl lease), and Union oil companies. The area lies just at the bend of the strata from a southeasterly to an easterly strike, in a structural depression analogous to a plunging syncline.

Zone B.—In the northern part of the area zone B is not over 15 feet thick in the wells; in the middle portion of the area it is 15 to 32 feet thick; and at the east end of the area it is 15 to 40 feet, although a total of 130 feet of oil-bearing strata, much of which is shale, is reported in this part of the field. In one well in the east end of the area the upper 6 feet of the productive sand is soft and yields a showing of oil, while the lower 9 feet is hard and yielded oil in commercial quantities. Near the northeast corner of sec. 13 two sands, separated by 80 feet of clay, occur in the wells. The upper sand is about 20 feet thick, is medium-grained, and carries gas and oil in commercial quantities; the lower sand is thinner and yields heavy oil and tar. A dark-colored shale in the top of zone B or immediately above it yields oil in some of the wells in the north end of the area. The product is called "shale oil" by the operators. This horizon is probably the one yielding oil of 16° to 18° Baumé in wells to the north.

Zone A.—Zone A usually extends to about 220 feet above the top of zone B, and contains several sands 5 to 20 feet thick intercalated with greater thicknesses of shale and clay. A parting of 60 feet of

shale or clay, with a hard shell at the base, separates zones A and B. The petroliferous layers vary from medium coarse sand to gravelly layers and some beds carrying cobbles of considerable size. Gas, oil, and tar are contained in the sands of zone A, the oil usually occurring in the lower sands and gas in the upper, although gas occurs in all of the petroliferous layers in greater or less quantities. Sulphur water is occasionally associated with the tar sands in the upper part of the zone.

Beds above zone A.—Blue clay with intercalated layers of sand, water sand, cobbles, and hard shell overlies zone A. The cobbles are more abundant in the southern part of the area than in the northern and central.

Water sands.—The abundance and productivity of the water sands are the most important characteristics of this area. This is to be expected where the wells penetrate a syncline, for, according to the well-known law of underground waters, they seek the lowest positions in the strata—that is, the bottoms of synclines. The zone of the water sands usually begins at about 120 feet below the surface, and from six to eight layers or lenses are encountered down to the top of zone A, from which the lowest water sand is separated by 15 to 60 feet of clay. The upper part of zone A also contains water in a few of the wells. The water sands are each from 5 to 40 feet thick and vary in composition from coarse sand to gravel carrying cobbles. The water is highly mineralized, much of it containing appreciable quantities of sulphur.

Water also occurs immediately below zone B in some parts of the area, especially near the axis of the syncline formed by the northeast and north-dipping beds. Such a condition calls for care in the operation of the wells in the affected territory, for too deep drilling is almost sure to result in a flooding of the productive sands by this "bottom water." Not only immediately below zone B, but still deeper, water occurs in sands interbedded with the shale. One well in the western part of the SW. ¼ sec. 18, T. 11 N., R. 23 W., struck hot sulphur water at a depth of about 1,700 feet.

Product.—The product of the various wells in this area ranges from tar just soft enough to flow to black oil of 16° to 17° Baumé gravity. The average for the shallow wells is about 11° to 12° Baumé; for the deeper ones about 15° or above. The heavy tar occurs in the shallow wells near the outcrop of the oil sands, the quality of the oil improving rapidly as the strata are tapped at greater and greater depths. Gas accompanies the oil in all the wells, but the pressure is not as great as in the areas to the north.

Production.—The production of most of the wells is light, usually under 25 barrels per day per well. Some of the deeper ones are said to promise 50 barrels when properly tested. This low pro-

duction is also a feature that is to be expected in wells penetrating the trough of a syncline, if the conditions postulated for the anticlinal theory prevail in the area. Very little sand, as compared with the areas to the north, occurs in the oil in this territory.

Methods.—The wells in this area vary in depth from 10 or 12 feet in the area of dug wells in the asphalt outcrops to over 1,800 feet in the deeper territory. Water is usually shut off in the wells just above zone B. The oil is obtained by pumping and even by bailing in the dug wells. The gas pressure being low, the sand is not as troublesome as in wells where the pressure is great enough to cause the wells to flow.

Typical logs.—The following log is characteristic of the northwestern part of the area:

Log of well in central part of the S. ½ sec. 1?, T. 11 N., R. 24 W.

	Feet.
Surface formation, hard gray sand with a little water	180
Shale and hard sand with increase of water	242
Brown sandstone	262
Hard shell	264
Soft gray sand	282
Black shale	292
Gray sand with increase of water	322
Blue sandy mud	367
Reddish-brown clay	380
Gray sandy mud, hard, odor of sulphur	395
Gray sandy clay, softer, little water	525
Black shale	535
Gray sand	660
Brown sandy shale	680

A typical log of the central part of the area, showing in addition to the oil sands the formation under them, is as follows:

Log of well in northwestern corner of SW. ¼ sec. 18, T. 11 N., R. 23 W.

	Feet.
Surface formation, alternating shale, yellow clay, sand, and brown shale	445
Blue shale	460
Yellow formation, water	480
Blue and yellow clay	567
Yellow water sand	573
Yellow clay	581
Blue clay	601
Blue water sand	612
Blue soft sand	621
Sticky blue clay	645
Blue water sand	654
Blue sandstone	670
Sticky blue clay	730
Fine loose sand (sulphur)	734
Stiff blue clay	740
Blue sand (much water), little gas and oil	748

	Feet.
Soft blue clay	756
Blue clay with gravel	760
Hard shell	761
Fine sand and clay	766
Coarse gravel	768
Blue clay	782
Tar sand, little gas	788
Blue clay, soft	800
Hard shell	801
Tar sand	803
Hard shell	807
Tar sand	809
Blue formation clay	835
Brown sand, coarse gravel, with oil	843
Hard shell	847
Brown sandstone with pockets of gas and oil	851
Tar sand and cobbles	861
Blue clay	871
Hard shell	872
Blue clay	960
Blue clay and gravel	962
Hard shell (drilled slow)	965
Brown sandstone, soft	986
Hard shell	989
Brown shale	994
Gray sand with water and gas	1,052
Brown shale	1,054
Brown shale with water	1,135
Reddish-brown shale (more gas)	1,144
Brown shale (caving)	1,384
Brown shale	1,292
Brown shale with thin strata of fine sand	1,330
Brown shale, harder	1,370
Brown shale with streaks of water	1,396
Hard sandy shell	1,401
Soft brown shale with a little water	1,413
Brown shale	1,537
Brown shale, softer	1,561
Gray sand with water	1,580
Gray sandy shale	1,595
Hard shell	1,597
Brown shale	1,671
Brown shale with fine sand and water	1,716
Brown shale	1,728
Hard shell	1,736
Hot sulphur water	1,750
Brown shale	1,785
Gray sand	1,797

DEVELOPED AREA SOUTHEAST OF SUNSET.

Location.—This area embraces the region for about 2 miles southeast of the Navajo wells and includes secs. 17, 20, 21, and 28, T. 11 N., R. 23 W. The territory has been affected by a number of profound faults, which have, among other results, brought the petroliferous diatomaceous shales up to the surface in the northern parts of secs. 20 and 21, where one would expect to find the McKittrick formation if the strike of the beds were constant eastward from the Navajo wells. It is from these siliceous shales that the wells in what are termed "group 2" in the following notes derive their oil. Unfortunately, much of the region under discussion is covered by alluvial and stream deposits of recent origin, so that it is impossible to discover the relations between these shale areas (represented as asphalt on the map, Pl. I) and the adjacent younger beds.

Description of developments.—At the time of the writers' visit to this area all the wells were abandoned. The shallow ones which were put down in the asphalt-impregnated shales had seeped full of heavy tar; the deeper ones were either clogged with débris or contained water. The following description of the developments in this area is by W. L. Watts,[a] who visited this region in 1893:

Messrs. Jewett and Blodgett bored two groups of wells in the mesa lands of the Sunset Oil district. One of these groups, "group 1," is in the NW. ¼ sec. 21; and the other, "group 2," is in the NE. ¼ sec. 28. In group 1 there are 13 wells, 1 of these being 1,300 feet in depth, the remainder varying from 80 to 500 feet in depth. The 1,300-foot well yielded flowing water and much gas; the others yield a heavy oil by pumping. The 12 oil-producing wells are all situated within an area of about 400 feet in length and 30 feet in width. The 1,300-foot well was bored a short distance in a northeasterly direction from the most northerly of the oil-yielding wells. The 12 oil wells yield altogether about 15 barrels of oil every twenty-four hours. The specific gravity of this oil varies in the different wells from about 12° Baumé to a heavy liquid asphaltum that requires to be heated by steam, which is forced to the bottom of the well before the heavy oil can be pumped. Six of these are dry wells, and are sunk to a depth of from 80 to 100 feet. The stratum yielding the greater portion of the heavy oil is about 35 feet in thickness. The other 6 are drilled wells, varying from 150 to 500 feet in depth. All of these wells are sunk to a sufficient depth to form reservoirs at the bottom capable of storing the oil which gathers during several days, for a few hours of pumping is sufficient to pump the oil accumulated during twenty-four hours.

The following records show the character of the formation penetrated by the wells belonging to group 1:

Well No. 1.

Bored in March, 1891. This well was commenced with 11-inch casing.

	Feet.
Surface drift	50
Light-colored shale	400
At this depth mineral water rose to within 40 feet of the top of the casing.	
Black sandy shale	559
At this depth the diameter of casing was reduced to 8⅝ inches.	

[a] Bull. California State Min. Bur. No. 3, 1894, pp. 27 et seq.

	Feet.
Black sandy shale with black sulphur water	610
At this depth casing reduced to 6⅝ inches.	
Black sandy shale	700
Gas from this depth burned with a flame 4 feet high from a 7-inch pipe.	
Black sandy shale, with oil in seams	900
At this depth casing reduced to 5⅝ inches.	
Very light-colored shale, to a depth of	928
Gray sand rock, with flowing water, to a depth of	995
At this depth the well flowed 50 barrels of mineral water daily and yielded much gas but little oil.	
Light-colored shale, to a depth of	1,235
Dark-colored shale, which caved badly, to a depth of	1,250
At this depth casing reduced to 4¾ inches.	
Dark-colored shale, to a depth of	1,290

The first gas was noticed at a depth of 600 feet, and two other distinct flows were struck at depths of 928 and 1,200 feet, respectively.

Well No. 4.

	Feet.
Asphaltum	50
Drift from the mountain	65
Shale, with some oil	70
Dark-colored shale and oil	130
Dark-colored shale, without oil	160
Light-colored shale	237

About 40 or 50 barrels of mineral water flowed from this well daily.

Well No. 6.

	Feet.
Wash and drift	30
Dark shale and oil	75
Dark shale, without oil	120

The boring ended in light shale. There was no water in this well.

In 1892–93 Messrs. Jewett and Blodgett bored three wells on the mesa lands in sec. 28, at a point a little more than a mile distant from group 1 and in a southeasterly direction therefrom. The following record shows the character of the formation penetrated:

Well No. 3.

This well is situated about 150 paces a little east of south from well No. 2.

	Feet.
For the first 300 feet a similar formation was penetrated to that passed through in wells Nos. 1 and 2	300
Bluish gray sandstone, with an occasional streak of darker-colored and sharper sand	755
At this depth there was much gas and a little oil. At the depth of 540 feet the water was shut off with 6⅝-inch casing.	
Brown sand, with considerable oil	815
Barren sandstone	940
Oil-bearing sandstone	950
Light-blue sand	1,030
At this depth a blue clay impeded drilling.	
Dark-blue sandstone, with more gas	1,060
Light-blue sandstone, with more gas	1,180
At this depth there was an increase in the amount of gas and oil.	

	Feet.
Sandstone	1,210
Black shale	1,215
Sandstone	1,220
Close-grained shale, with more oil	1,270
Oil sand	1,295
Coarse sand	1,350

It is the gas from this well which was used in the experiments on the fuel value of the gas at Sunset.

The oil yielded by the oil wells of group 2 is a dark-green oil and possesses a lower specific gravity than that yielded by the oil wells of group 1.

The Nevada Pacific Oil Company has just drilled a well in the SW. ¼ SW. ¼ sec. 24, T. 11 N., R. 23 W., in which a heavy tar was encountered in a coarse clean sand at about 500 feet below the surface. This well is the farthest east in the district that has encountered tar or oil.

OIL COMPANIES AND OIL WELLS IN SUNSET DISTRICT.

In the following list of companies and wells the locations refer to the San Bernardino base and meridian.

Oil companies and oil wells in the Sunset district.

Name of oil company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Adeline		1	SE. ¼ sec. 2, T. 11 N., R. 24 W	830
Do		2	do	830
Do		3	do	830
Do		4	do	
Do		5	do	830
Do		6	do	830
Do		7	do	830
Do		12	do	
Do		13	do	837
Do		24	do	840
Do		25	do	845
Do	Superior	1	SE. ¼ sec. 2, T. 11 N., R. 24 W	840
Do	do	2	do	830
Do	do	3	do	840
Alpha (*see* Union)	Alameda			
Arcola		1	SW. ¼ sec. 2, T. 11 N., R. 24 W	975
Do		2	do	950
Do. (water well)			do	975
Do	Euclid	1	SW. ¼ sec. 2, T. 11 N., R. 24 W	975
Arcola Extension	Dirigo	1	SE. ¼ sec. 2, T. 11 N., R. 24 W	850
Do	do	2	do	830
Barrett. (*See* Union.)				
Bronco		1	NW. ¼ sec. 8, T. 11 N., R. 23 W	
Beaver		1	N. ½ sec. 34, T. 12 N., R. 24 W	936
Do		2	do	970
Do		3	do	992
California Diamond	Obispo	1	NW. ¼ sec. 2, T. 11 N., R. 24 W	995
Do		2	do	1,000
Do		3	do	980
California Fortune. (*See* Tannehill.)				
California King	Yellowstone	1	NE. ¼ sec. 7, T. 11 N., R. 23 W	
Catfish. (*See* Union.)				
Charter. (*See* Union.)				
Chicago Guarantee. (*See* Union.)				
Conservative	Lion	1	SE. ¼ sec. 12, T. 11 N., R. 24 W	830
Do	do	2	do	825
Colorado and California Fuel. (*See* Union.)				
Dahlia. (*See* Union.)				
Dirigio. (*See* Arcola Ext.)				
Dunn & Barrett	Wiethase	1	SE. ¼ sec. 8, T. 11 N., R. 23 W	
El Rey		1	NE. ¼ sec. 2, T. 11 N., R. 24 W	890±
Essex		1	NE. ¼ sec. 6, T. 11 N., R. 23 W	
Ethel D	R. E. Graham	1	SE. ¼ sec. 36, T. 12 N., R. 24 W	

Oil companies and oil wells in the Sunset district—Continued.

Name of oil company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Ethel D	R. E. Graham	2	SE. ¼ sec. 36, T. 12 N., R. 24 W.	
Euclid. (*See* Arcola.)				
Federal Crude. (*See* Union.)				
Fulton		1	SW. ¼ sec. 1, T. 11 N., R. 24 W.	835
Do		2	do	838
Do		3	do	832
Do		4	do	842
Do		5	do	829
Do		6	do	847
Do		7	do	803
Do		8	do	810
Do. (water well)			do	840
Do		9	do	
Do		10	do	
Do		11	do	
Gate City		1	SW. ¼ sec. 1, T. 11 N., R. 24 W.	830
Do		2	do	840
Do		3	do	838
Do	Maricopa	1	SW. ¼ sec. 1, T. 11 N., R. 24 W.	830
Do	do	2	do	829
Do	do	3	do	847
Do	do	4	do	840
Do	do	5	do	847
Do	do	6	do	
Do	do	7	do	
Do	do	8	do	
Do	do	9	do	
Do	do	10	do	
Golden Gate. (*See* Union.)				
Golden West		1	SE. ¼ sec. 12, T. 11 N., R. 24 W.	782
Do		2	do	
Graham & Sinter	Wiethase	1	SW. ¼ sec. 8, T. 11 N., R. 23 W.	
Do	do	2	do	
Graham, Frank		1	SE. ¼ sec. 10, T. 11 N., R. 23 W.	
Do		1	SW. ¼ sec. 12, T. 11 N., R 23 W.	
Do		1	SW. ¼ sec. 14, T. 11 N., R. 23 W.	
Do		1	SW. ¼ sec. 15, T. 11 N., R. 23 W.	
Hanford Sanger. (*See* Monarch Eagle.)				
Do		2	do	995
Hazelton Crude		1	SW. ¼ sec. 17, T. 11 N., R. 23 W.	
Hazelton Water. (*See* Union.)				
Hill Well. (*See* Union.)				
J. B. & B. (*See* Union.)				
Jewett & Blodgett. (*See* Union.)				
Johnson	Graham & Sinter.	1	NE. ¼ sec. 8, T. 11 N., R. 23 W.	
Do	do	2	do	
Do	do	3	do	
Do	"400"	1	SE. ¼ sec. 7, T. 11 N., R. 23 W.	675
K. T. & O	C. E. Graham	1	NE. ¼ sec. 1, T. 11 N., R. 24 W.	
Do	do	2	do	
Do	do	3	do	
Do	do	28	do	
La Blanc	Sunset Ext	1	NW ¼ sec. 6, T. 11 N., R. 23 W.	
Lady Washington No. 1	Haviland	1	SW. ¼ sec. 6, T. 11 N., R. 23 W.	718
Lady Washington No. 2	Yellowstone	2	NW. ¼ sec. 7, T. 11 N., R. 23 W.	684
Lion. (*See* Conservative.)				
Loma Vista	Kern Sunset	1	NE. ¼ sec. 12, T. 11 N., R. 24 W.	810
Do	do	2	do	810
Do	do	3	do	
Do	do	4	do	
Maricopa-McKittrick Cons'd.		1	NW. ¼ sec. 36, T. 12 N., R. 24 W.	
Do		2	do	
Main Line		1	SE. ¼ sec. 6, T. 11 N., R. 23 W.	
Manitoba	Yellowstone	1	NE. ¼ sec. 7, T. 11 N., R. 23 W.	
McCutcheon	Petroleum Center.	1	NE. ¼ sec. 2, T. 11 N., R. 24 W.	818
Do	do	2	do	812
Do	do	3	do	
Do		1	NE. ¼ sec. 2, T. 11 N., R. 24 W.	820
Do		2	do	830
Do		3	do	818
Do		4	do	815
Do		5	do	
Do		6	do	
Mohawk-Sunset		1	SE. ¼ sec. 1, T. 11 N., R. 24 W.	
Monarch Eagle	Hanford-Sanger	1	NE. ¼ sec. 3, T. 11 N., R. 24 W.	990
Do	do	2	do	995
Do	do	3	do	
Monte Cristo	Pittsburg	1	NW. ¼ sec. 1, T. 11 N., R. 24 W.	795
Do		2	do	788

Oil companies and oil wells in the Sunset district—Continued.

Name of oil company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Monte Cristo		3	NW. ¼ sec. 1, T. 11 N., R. 24 W.	804
Do.		4	do.	780
Do.		5	do.	800
Do.		6	do.	781
Do.		7	do.	817
Do.		8	do.	779
Do.		9	do.	826
Do.		10	do.	773
Do.		11	do.	832
Do.		12	do.	776
Do.		13	do.	840
Do.		14	do.	
Do.		15	do.	838
Do.		16	do.	
Do.		32	do.	
Munzer		1	NW. ¼ sec. 7, T. 11 N., R. 23 W.	
Muscatine		1	SE. ¼ sec. 1, T. 11 N., R. 24 W.	
Do.		2	do.	
Do.		3	do.	
Nanticoke. (*See* Union.)				
Nevada Pacific		1	SW. ¼ sec. 24, T. 11 N., R. 23 W.	
New Center		1	NW. ¼ sec. 12, T. 11 N., R. 24 W.	830
Do.		2	do.	805
Do.		3	do.	806
Do.		4	do.	816
Do.		5	do.	808
Do.		6	do.	805
Do.		7	do.	815
Do.		8	do.	820?
Do.		9	do.	
Do.		10	do.	820?
Northern		1	NE. ¼ sec. 12, T. 11 N., R. 24 W.	755
Do.		4	do.	760
Obispo		1	SW. ¼ sec. 32, T. 12 N., R. 23 W.	
Occidental	Sunset Monarch	A	SW. ¼ sec. 7, T. 11 N., R. 23 W.	760
Do.	do.	B	do.	765
Do.	do.	C	do.	770
Do.	do.	D	do.	
Occidental. (*See* Sunset Monarch.)				
Pacific. (*See* Phoenix Refining.)				
Petroleum Center. (*See* McCutcheon.)				
Phoenix Refining. (*See* Union.)				
Pittsburg. (*See* Monte Cristo.)				
Queen (*See* Union.)				
Ruby		1	NE. ¼ sec. 2, T. 11 N., R. 24 W.	825
Do.		2	do.	817
Do.		3	do.	838
Do.		4	do.	810
Do.		5	do.	
Do.		6	do.	
Do.		7	do.	
Do.		8	do.	
Sage. (*See* Union.)				
Santa Rosa. (*See* Sunset Monarch.)				
Sedalia-California. (*See* Union.)				
Snook, Walter	Tiger	1	NE. ¼ sec. 12, T. 11 N., R. 24 W.	804
Do.		2	do.	808
Do.		3	do.	801
Do.		4	do	804
Stone. (*See* Union.)				
Sunset Acme	Reynolds (Acme).	1	SE. ¼ sec. 34, T. 12 N., R. 24 W.	1,025
Do.	do.	2	do.	1,009
Do.	do.	3	do.	1,020
Do.	do.	4	do.	1,010
Sunset Diamond. (*See* Union.)				
Sunset Monarch. (*See* Occidental.)	American Girl No. 1.			
Sunset Monarch	Occidental	1	NE. ¼ sec. 2, T. 11 N., R. 24 W.	940
Do.	do.	2	do.	935
Do.	do.	3	do.	925
Do.	do.	4	do.	935
Do.	do.	5	do.	
Do.	Santa Rosa	1	NW. ¼ sec. 2, T. 11 N., R. 24 W.	1,000
Do.	do.	2	do.	1,020
Do.	do.	3	do.	1,030

Oil companies and oil wells in the Sunset district—Continued.

Name of oil company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Sunset Monarch	Sunset Monarch	1	NW. ¼ sec. 2, T. 11 N., R. 24 W.	980
Do	do	2	do	975
Do	do	3	do	945
Do	do	4	do	940
Do	do	5	do	930
Do	do	6	do	940
Do	do	7	do	925
Do	do	8	do	842-942(?)
Do	do	9	do	890-900(?)
Do	do	10	do	850-890(?)
Do		A	SW. ¼ sec. 26, T. 12 N., R. 24 W.	876
Do		B	do	840
Do		C	do	900
Do	Transport	1	NE. ¼ sec. 2, T. 11 N., R. 24 W.	830
Do	do	2	do	825
Do	do	3	do	820
Do	do	4	do	820
Do	do	5	do	830
Do	do	6	do	830
Do	do	7	do	
Do	Tremont	1	NW. ¼ sec. 2, T. 11 N., R. 24 W.	900
Do	do	2	do	920
Do	do	3	do	890
Sunset Petroleum and Refining.		1	NE ¼ sec. 29, T. 11 N., R. 23 W.	
Sunset Queen		1	NW. ¼ sec. 14, T. 11 N., R. 24 W.	1,090
Sunset Rex		1	NE. ¼ sec. 2, T. 11 N., R. 24 W.	840
Do		2	do	842
Do		3	do	
Sunset Road. (*See* Union.)				
Superior. (*See* Adeline.)				
Tannehill	California Fortune.	1	NW. ¼ sec. 34, T. 12 N., R. 24 W.	1,120
Do	do	2	do	1,125
Do	do	3	do	1,120
Do	do	4	do	1,140
Do	do	5	do	1,150
Do	do	6	do	1,160
Do	do	7	do	1,120
Do		8	do	
Do		9	do	
Teck		1	NE. ¼ sec. 3, T. 11 N., R. 24 W.	990
Do		2	do	1,035
Do		3	do	980
Do		4	do	
Tiger. (*See* Snook, Walter.)				
Topaz		1	SE. ¼ sec. 12, T. 11 N., R. 24 W.	755
Do		2	do	724
Union	Alpha	(?) 1	NW. ¼ sec. 13, T. 11 N., R. 24 W.	800
Do	do	(?) 2	do	795
Do	do	3	do	780
Do	do	4	do	780
Do	do	5	do	780
Do	do	6	do	780
Do	do	8	do	780
Do	Barrett	1	SE. ¼ sec. 2, T. 11 N., R. 24 W.	850
Do	do	2	do	850
Do	Catfish	1	NE. ¼ sec. 33, T. 12 N., R. 24 W.	1,165
Do	do	2	do	1,230
Do	Charter	1	NE ¼ sec. 13, T. 11 N., R. 24 W.	785
Do	Chicago Guarantee	1	W. ½ sec. 18, T. 11 N., R. 23 W.	790
Do	do	2	do	820
Do	Colorado and California Fuel.	1	NW. ¼ sec. 35, T. 12 N., R. 24 W.	1,018
Do	do	2	do	1,034
Do	do	1	S. ½ sec. 12, T. 11 N., R. 24 W.	835
Do	do	2	do	830
Do	do	3	do	
Do	do	4	do	
Do	Crown	1	NE. ¼ sec. 13, T. 11 N., R. 24 W.	
Do	Dahlia	1	SE. ¼ sec. 35, T. 12 N., R. 24 W.	900±
Do	Federal Crude	1	NW. ¼ sec. 35, T. 12 N., R. 24 W.	1,018
Do	do	2	do	1,034
Do	Golden Gate	1	NE. ¼ sec. 34, T. 12 N., R. 24 W.	953
Do	Hazelton Water	1	NW. ¼ sec. 13, T. 11 N., R. 24 W.	
Do	do	2	do	800±
Do	Hill	1	SW. ¼ sec. 18, T. 11 N., R. 23 W.	775
Do	J. B. & B. (Sunset Road).	1	SW. ¼ sec. 35, T. 12 N., R. 24 W.	957
Do	do	2	do	952
Do	do	3	do	958
Do	do	4	do	929
Do	do	5	do	923

Oil companies and oil wells in the Sunset district—Continued.

Name of oil company.	Former name.	No. of well.	Locality.	Elevation.
				Feet.
Union	J. B. & B. (Sunset Road).	6	SW. ¼ sec. 35, T. 12 N., R. 24 W.	960
Do.	do.	7	do.	939
Do.	do.	8	do.	955
Do.	do.	9	do.	977
Do.	do.	10	do.	981
Do.	do.	11	do.	964
Do.	do.	12	do.	999
Do.	do.	1	NW. ¼ SW. ¼ sec. 35, T. 12 N., R. 24 W.	961
Do.	J. B. & B. (Navajo)	1	NW. ¼ sec. 20, T. 11 N., R. 23 W.	
Do.	do.	2	do.	
Do.	do.	3	do.	
Do.	do.	1	SW. ¼ sec. 11, T. 11 N., R. 24 W.	
Do.	do.	1	SE. ¼ sec. 34, T. 12 N., R. 24 W.	
Do.	J. B. & B. (Czar).	1	N. ½ sec. 19, T. 11 N., R. 23 W.	
Do.	J. B. & B. (Sunset King).	2		
Do.	Jewett & Blodgett.	17	SW. ¼ sec. 18, T. 11 N., R. 23 W.	820
Do.	Nanticoke	1	SE. ¼ sec. 27, T. 12 N., R. 24 W.	900+
Do.	Phœnix (Pacific)	1	SW. ¼ sec. 35, T. 12 N., R. 24 W.	945
Do.	do.	2	do.	936
Do.	Queen	1	NW. ¼ sec. 14, T. 11 N., R. 24 W.	775
Do.	Sage	1	E. ½ sec. 35, T. 12 N., R. 24 W.	794
Do.	do.	2	do.	792
Do.	do.	3	do.	774
Do.	do.	4	do.	748
Do.	do.	5	do.	825
Do.	do.	6	do.	825
Do.	do.	7	do.	
Do.	do.	8	do.	
Do.	do.	9	do.	
Do.	do.	10	do.	
Do.	Sedalia-California	1	W. ½ sec. 18, T. 11 N., R. 23 W.	775
Do.		2	do.	770
Do.		3	do.	765
Do.		4	do.	760
Do.		5	do.	765
Do.		6	do.	750
Do.		7	do.	750
Do.		8	do.	
Do.		9	do.	
Do.		10	do.	
Do.	Stone	1	SE. ¼ sec. 28, T. 12 N., R. 24 W.	1,240
Do.	Sunset Diamond	1	NE. ¼ sec. 13, T. 11 N., R. 24 W.	775
Do.	do.	2	do.	775
Do.	do.	3	do.	
Do.	Webster	1	SE. ¼ sec. 35, T. 12 N., R. 24 W.	796
Do.	do.	2	do.	892
Do.	do.	3	do.	907-923(?)
Do.	do.	4	do.	832
Do.	do.	5	do.	795
Do.	do.	6	do.	782
Do.	do.	7	do.	830
Do.	do.	8	do.	
Do.	do.	9	NW. ¼ sec. 35, T. 12 N., R. 24 W.	800
Do.	Wichita	1	SE. ¼ sec. 2, T. 11 N., R. 24 W.	850
Do.	do.	2	do.	850
Do.	do.	3	do.	
Do.	do.	4	do.	
United Crude		1	NE. ¼ sec. 2, T. 11 N., R. 24 W.	825
Do.		2	do.	830
Do.		3	do.	820
Do.		4	do.	818
Do.		5	do.	816
Do.		6	do.	814
Wellman	R. E. Graham	1	SW. ¼ sec. 36, T. 12 N., R. 24 W.	
Do.	do.	2	do.	
Do.	do.	3	do.	788
Do.	do.	4	do.	779
Do.	do.	5	do.	773
Do.	do.	6	do.	
Western Minerals		1	N. ½ sec. 17, T. 11 N., R. 23 W.	
Do.		2	do.	
Do.		1	SW. ¼ sec. 17, T. 11 N., R. 23 W.	910
Do.		2	do.	905
Do.		1	Sec. 12, T. 11 N., R. 23 W.	
Do.		1	N. ½ sec. 22, T. 11 N., R. 23 W.	
Do.		1	SW. ¼ sec. 23, T. 11 N., R. 23 W.	
Do.		1	N. ½ sec. 25, T. 11 N., R. 23 W.	
Do.		1	SW. ¼ sec. 26, T. 11 N., R. 23 W.	
Wichita. (*See* Union.)				

DEVILS DEN FIELD.

LOCATION.

The territory in which drilling operations have been carried on in the Devils Den district includes the central-eastern part of T. 25 S., R. 17 E., and secs. 22, 23, and 24, T. 25 S., R. 18 E. Among the operating companies have been the Spreckles Oil Company, the Devils Den Oil Company, and the Pluto Oil Company. (See list, p. 199.)

GEOLOGY.

The oil-bearing formation of the Devils Den district, as indicated by the tar springs in sec. 25, T. 25 S., R. 18 E., and by the well logs, is the Vaqueros sandstone or the sand lenses interbedded at the base of the shale of the Santa Margarita (?) formation. The Spreckles wells put down several years ago in the eastern part of sec. 24, T. 25 S., R. 17 E., and in the western part of sec. 30, T. 25 S., R. 18 E., penetrated the Cretaceous rocks (Knoxville-Chico) but obtained no petroleum. The logs of but two wells were available in the study of this district. They are given below and indicate that the oil zone is overlain by white and brown shales, in which are hard yellow concretionary layers. The sand itself is quite hard and rather coarse-grained, consisting largely of quartz. The oil-bearing beds occur as a monocline passing in a northwest-southeast direction through secs. 11, 13, 14, and 24, with a somewhat similar monocline passing in an east-west direction through secs. 22, 23, and 24. The first monocline becomes the northeastern flank of an anticline in sec. 14, and this anticline passes into the monocline of secs. 22 and 23.

PRODUCT AND PRODUCTION.

The products of the wells are of two qualities. The sands intercalated with the shales produce an oil said to have a gravity of about 23° Baumé, while the underlying coarser sand of the Vaqueros yielded much heavier oil or tar. Neither well has been properly tested for production, but the one producing the light oil was estimated to be capable of yielding about 10 barrels per day.

It is stated that a thick oil has been struck at a depth of 400 feet by the Pluto Oil Company, in the NW. ¼ sec. 19, T. 25 S., R. 19 E.

WELL LOGS.

The following logs of the two wells which had been drilled in the district previous to the visit of the writers in the summer of 1908 were kindly furnished by Prof. O. D. Barton, of Dudley:

Log of Devils Den Oil Company well No. 1, in the NE. ¼ sec. 23, T. 25 S., R. 18 E., Devils Den district (drilled in 1901).

	Feet.
First water	45
Second water, rose within 15 feet of surface	78
Top of reef (Vaqueros)	426
Reef proper, hard, carries heavy oil	427–431
Oil sand, oil heavy, stuck to tools, lighter than that above	431–446
Hard reef	446–460
Sand carrying water like tar spring	460–636
Light-colored shale	636–780

Log of Niagara Oil Company well No. 1, in NW. ¼ sec. 22, T. 25 S., R. 18 E., Devils Den district.

	Feet.
White shale	100
Yellow shale, hard	104
White shale	304
Dark brown shale	329
Hard silicified shale	332
Oil sand (estimated 23° Baumé gravity, carried oil all the way, estimated at 10 barrels per day)	372
Sand with water	600
Reef of hard sandstone	603
Water sand	708
Hard sand, limy	709
Streak of good water	960
Blue shale (drilling)	1,145

OIL COMPANIES AND OIL WELLS.

The following list of the oil companies operating in the Devils Den district, with the location of their wells, has been corrected up to December 25, 1909, by Mr. Guy H. Salisbury.

Oil companies and oil wells in Devils Den district.

Name of oil company.	Number of wells or rigs.	Locality.
Colt	1 well	SW. ¼ sec. 5, T. 25 S., R. 19 E.
Cosmos	do	SE. ¼ sec. 31, T. 25 S., R. 19 E.
Devils Den Consolidated	2 wells	NW. ¼ sec. 22, T. 25 S., R. 18 E.
Dominion		S. ½ S. ½ sec. 7, T. 23 S., R. 17 E.
Dougherty & Johanson	1 well	Sec. 2, T. 26 S., R. 19 E.
East Oakland	do	NW. ¼ sec. 2, T. 26 S., R. 18 E.
Etzenhause	do	Sec. 27, T. 24 S., R. 18 E.
Gibraltar (operating company)	1 rig	SW. ¼ sec. 5, T. 24 S., R. 18 E.
Greasy Jim	1 well	SE. ¼ sec. 9, T. 25 S., R. 18 E.
Do		S. ½ sec. 15, T. 25 S., R. 18 E.
Kerns & Berry	1 well	SE. ¼ sec. 26, T. 25 S., R. 19 E.
Lindsay (Incorporated)	do	SW. ¼ sec. 9, T. 25 S., R. 18 E.
Lovelace & Rarr	do	NE. ¼ sec. 27, T. 25 S., R. 19 E.
Do		SW. ¼ sec. 26, T. 25 S., R. 19 E.
Marathon	1 well	NE. ¼ sec. 13, T. 25 S., R. 18 E.
Pluto	do	NW. ¼ sec. 19, T. 25 S., R. 19 E.
Positive	1 rig	NE. ¼ sec. 31, T. 25 S., R. 19 E.
Swastika (holding company)		S. ½ sec. 5, T. 24 S., R. 18 E.
Tres Cerritos	1 well	SW. ¼ sec. 13, T. 25 S., R. 18 E.
Do	do	SW. ¼ sec. 15, T. 25 S., R. 18 E.
True Blue	do	Sec. 24, T. 25 S., R. 18 E.
Walker	1 rig	NW. ¼ sec. 29, T. 25 S., R. 19 E.
West Side Oil and Development.	1 well	SW. ¼ sec. 2, T. 25 S., R. 19 E.

TEMBLOR FIELD.

LOCATION.

The Temblor field occupies the low hills northwest of McKittrick as far as the Carneros Springs. It includes the northeastern part of sec. 29 S., R. 20 E., and the southeastern part of T. 29 S., R. 21 E. The companies which have drilled or are now operating in this district are, among others, the Associated, De Groot, Section Six (formerly Climax), and Springfield.

STRUCTURE.

The principal lines of structure affecting the territory under discussion are the Temblor anticline, and an anticline here called the "Gould," which passes from sec. 13, T. 29 S., R. 20 E., eastward to sec. 17, T. 29 S., R. 21 E., and thence in a southeasterly direction to the hills in front of Frazer Spring. The location of the axis of this last anticline across the Temblor Valley is hypothetical, as stream wash covers the area in question. Many local folds and faults complicate the structure. These are shown on the map and will not be described in detail. The Temblor anticline begins in sec. 26, T. 29 S., R. 20 E., and passes easterly to sec. 32, T. 29 S., R. 21 E., where it becomes somewhat sinuous. It is not possible to trace the axis continuously between the two sections mentioned, but the general geologic features of the region clearly indicate that the anticline exists as described, and suggests that faults are associated with it. The only productive wells so far encountered in the southern part of the field are along or near the axis of this anticline.

OIL SANDS.

The productive sand in the Temblor field is of Vaqueros (lower Miocene) age and in surface outcrops is about 200 to 400 feet in thickness. Tar springs and asphalt deposits mark the trace of this sand near the axis of the Temblor anticline in sec. 36, T. 29 S., R. 20 E.

OIL WELLS.

It is near the tar springs in sec. 36 that most of the productive wells of the field are drilled. These wells are from about 250 to more than 535 feet deep. The oil sand is encountered at depths ranging from a little more than 200 feet to about 400 feet, and is penetrated in the wells 24 to 100 feet. The sand is coarse and consists of quartz grains, and in places carries small pebbles of granite and metamorphic rock. Shale partings sometimes occur between the sand layers. These partings are thin and important in separating the oil from the water which is found in the oil zone.

Several other wells besides those mentioned as having been drilled on sec. 36 have been put down at various points along the Temblor anticline, in the shale area east of it. The logs of the wells put down in the shale indicate that the formation above the oil zone is, except for a few insignificant sand lenses, entirely shale. None of these wells is said to have yielded oil except the De Groot, near the center of the NW. ¼ sec. 32, T. 29 S., R. 21 E., and in this the occurrence of oil is more or less questionable. It is said that this well is more than 1,300 feet deep and penetrates the oil sand near the bottom.

Several wells which obtained no oil and were later abandoned were at one time drilled in the region north of the Temblor ranch. Among these is one in the northeast corner of the SW. ¼ sec. 24, T. 29 S., R. 20 E., which now contains water. Blue shale found on the sump adjacent to this well indicates the character of the beds penetrated by the drill. Although the well starts in the shale only a short distance above the reef bed, the strata here dip so deeply that the reef was never encountered in the well. Another abandoned well, in the SE. ¼ sec. 17, T. 29 S., R. 20 E., yields about one-half inch of salt water. This well is capped and produces a hissing sound as the water flows out, indicating a considerable gas pressure. No odor is perceptible in the vicinity, so it is unlikely that the gas contains much sulphur.

Several wells have been drilled on the north flank of the Gould anticline in sec. 12, T. 29 S., R. 20 E., and sec. 7, T. 29 S., R. 21 E. The wells in the last-mentioned section penetrate the diatomaceous shale of the Santa Margarita(?) and yield small quantities of oil. No data are available concerning the logs of these wells or the amount or quality of the oil produced, but conditions around the abandoned property indicate that the wells were shallow and the production not large. It is believed that the best production in this area will be obtained from a 20-foot stratum of oil sand at the base of the McKittrick formation overlying the diatomaceous shale just mentioned. The wells in sec. 12, T. 29 S., R. 20 E., penetrate the Miocene shale and are said to have attained a depth of nearly 2,000 feet, encountering 15 to 20 feet of oil sand near the bottom. It is believed that this sand lies near the base of the Monterey formation, and had the drills gone far enough below this they would probably have encountered the more productive sand at the top of the Vaqueros (lower Miocene).

PRODUCT AND PRODUCTION.

The product of those wells which have penetrated the oil-bearing beds consists of black oil varying in gravity from about 14° up to 20° Baumé. The production of the wells in sec. 36, T. 29 S., R. 20 E., varies from a few barrels to over 60 barrels a day. Large quan-

tities of sulphur water accompany the oil from the wells. The occurrence of the water with the oil is probably accounted for by the failure of the drillers to shut off the water and by the fractured condition of the beds adjacent to the faulted anticline which passes near the wells. It is believed that wells which may penetrate the oil zone at a distance from the anticline in this locality will encounter more favorable conditions.

CARRIZO PLAIN FIELD.

LOCATION.

The region generally known as the "Carrizo Plain district" embraces Carrizo and Elkhorn plains and the adjacent southwestern flank of the Temblor Range. The supposed oil territory occupies the flanks of the hills toward the base of the range and the edge of the Carrizo and Elkhorn plains.

GEOLOGY.

The oil in the Carrizo Plain district occurs in sandstones interbedded with the base of the Monterey shale, or at the top of the Vaqueros, or in beds unconformably overlying the Monterey and Vaqueros. The Vaqueros sandstones are coarse and consist largely of quartz grains, with occasional granite and black to varicolored quartzite pebbles. The sandstone is roughly concretionary, the concretions sometimes attaining a diameter of 10 or 15 feet. The beds carrying oil, which unconformably overlie the Vaqueros and Monterey, consist of granitic débris and rounded shale fragments. The shallow wells, of which all the successful ones penetrate the base of the Monterey or the top of the Vaqueros, have in most instances been put down close to the axis of those anticlines which have an arched top and steep-dipping sides. There are several of these anticlines (shown on the map, Pl. I) which expose the Vaqueros sandstone or bring it close to the surface. Faults accompany most of the anticlines, and so complicate the structure that predictions concerning the territory a short distance away from the axis of an anticline are extremely hazardous.

An oil sand consisting of shale and other pebbles associated with granitic sand, and believed to be of later age than the Monterey, is exposed in the southern part of the area. A particularly advantageous place for studying this is about one-half mile west of the Vishnu well, in the southern part of sec. 22, T. 32 S., R. 22 E. The sand here is probably over 15 or 20 feet thick, and is overlain by fine-grained brown shales. This oil sand lies in a syncline, near the eastern edge of which the Vishnu well has been put down. It is believed that the Vishnu well obtains its oil from the Monterey or Vaqueros many hundreds of feet below the sand just described.

OIL WELLS.

No commercially productive wells have been drilled in the district, but several prospect wells have. Among these, beginning at the northwest, are the R. M. Smith well No. 1, in the northeast corner of sec. 21, T. 30 S., R. 20 E.; the seven wells of the R. M. Smith Oil Company, near the corner stake of secs. 22, 23, 26, and 27, T. 30 S., R. 20 E.; the Cree well, in the southwest corner of sec. 22, T. 31 S., R. 21 E.; the Erume test holes, in the southern part of the same section; the Schwartz well of the Union Company, near the southeast corner of sec. 6, T. 32 S., R. 22 E.; and the Sperry or Vishnu well, in the southeast corner of sec. 22, T. 32 S., R. 22 E.

The R. M. Smith wells in secs. 22, 23, 26, and 27, T. 30 S., R. 20 E., the Erume wells in sec. 22, T. 31 S., R. 21 E., and the Vishnu well, in sec. 22, T. 32 S., R. 22 E., have yielded traces of oil. The Smith and Erume wells are shallow and have yielded oil only in small quantities. The oil is of a good quality, and is said to test about 28° Baumé gravity, although occurring within less than 100 feet of the surface. It is brownish to greenish in color and has very little viscosity. It is said that this oil is used in its native condition in lamps, making a somewhat smoky flame, however. Nothing definite is known concerning the quality of the oil encountered in the Sperry well, but it is said to have been of very good quality and of about 30° Baumé gravity.

FUTURE DEVELOPMENT.

GENERAL STATEMENT.

The conclusions here to be discussed as to the course that future development will take in the McKittrick-Sunset region are based on a belief that the petroleum in the Devils Den district is largely derived from the shales of the Tejon formation and the overlying Oligocene(?) rocks, and that on migration it collects in the sands in the Vaqueros (lower Miocene) formation, which lies above the two formations first mentioned; and that the petroleum in the territory from the Antelope Valley southward is derived from the shales of the Monterey and Santa Margarita(?) formations, and that on migration it collects in the sands at the base of or underlying the Monterey formation—that is, in the sands of the Vaqueros; in sand lenses in the Santa Margarita(?); and also in the porous beds at the base of the McKittrick, which unconformably overlies the older formations. All the conditions indicate that this belief is well founded.

The accumulation of the petroleum and the possibility of its extraction in commercial quantities depend on several prerequisite factors. Among these are the following, briefly stated:

(*a*) An adequate thickness of the shales forming the original source of the oil, to yield commercial quantities of petroleum.

(*b*) A cause for the migration of the oil from its source in the organic shales. This cause is believed to be supplied by the tendency of oil to migrate by diffusion through certain media, such as dry shales; it may be and doubtless is in certain instances augmented by hydrostatic pressure wherever water has come into contact with the petroleum.

(*c*) Associated porous beds occupying such a position relative to the source of the oil and to impervious barriers as to permit the petroleum to pass from the source into the final reservoir, and there to be confined by impervious strata. Wet shale or clay and certain fine-grained water-impregnated sands are believed to be among the effective barriers to the migration of the oil.

(*d*) Occurrence of the accumulations at a depth far enough below the surface and distant enough from outcrops to preclude the escape of the lighter hydrocarbons, and still at depths which may be profitably reached by the drill.

The areas within the lines shown on the map (Pl. I) as bounding the possible productive territory are those in which the top of the supposed oil zone has been calculated as within a vertical distance of 5,000 feet from the surface, but excluding some areas (to be mentioned specifically) where the probability of the occurrence of petroleum at any depth whatever decreases with the distance from a given locality. For these exceptional places the depth limit is lessened as the probability of occurrence of petroleum decreases, in order that any locus of points of equal probability may be kept at about equal distance from the line limiting the supposed oil territory. For example, the probability is strong that the zone of the oil sands (Vaqueros or lower Miocene in the locality specified) will be struck at a depth considerably less than 5,000 feet (possibly 3,000 feet) at the southwest corner of sec. 10, T. 26 S., R. 19 E., or less than the depth at which it will be struck at the middle of the north line of sec. 29, T. 25 S., R. 19 E.; but the probability that the zone of the oil sands carries commercial quantities of petroleum is much less in sec. 10 than in sec. 29. To compensate for this greater risk, the line supposed to limit the practicable oil territory is brought equally near to both points, by means of a progressive lessening of the depth limit toward the sec. 10 locality.

A depth of 5,000 feet below the surface has been arbitrarily taken as the maximum to which it is possible to drill by present methods in the region under discussion, as this is about the maximum depth of holes in California that have been drilled with a standard rig. It may be possible to go deeper, but for the present this limit seems sufficiently great. Whether or not a well can be profitably drilled

depends upon so many factors, such as quantity of oil produced compared with cost of drilling, price of oil, etc., that local conditions must determine the result in each specific case.

It seems very unlikely that oil in commercial quantities will be found in any of the rocks underlying the Vaqueros (lower Miocene), that is, in the Tejon (Eocene), Knoxville and Chico (Cretaceous), or Franciscan formations (see map, Pl. I), while it is quite likely that it will be found in the Vaqueros (lower Miocene) in certain portions of the Devils Den district, and in the Vaqueros sandstone in the Temblor Range south of a line in general coincident with the south line of T. 28 S., and that it will be found also in the basal McKittrick beds throughout the region on the northeastern flank of the Temblor Range south of Media Agua Creek in the eastern part of T. 28 S., R. 19 E. Whether or not the oil will be found in paying quantities in the formations mentioned will depend on the factors enumerated above. In the following paragraphs it is the intention of the writers to give their personal opinion as to the probabilities of the occurrence of petroleum in regions not yet thoroughly tested by the drill. It must be borne in mind, however, that absolute determination, by work on the surface, of the occurrence or nonoccurrence of oil in any one locality is not possible. The best that can be done is to calculate the degree of probability on the basis of surface indications and structural conditions.

The conclusions reached concerning future development form the basis for the classification of the government land within this region into mineral and nonmineral. This classification is indicated graphically on the map (Pl. I), the mineral land being inclosed by the heavy lines, while that not so inclosed is believed to offer little or no inducement for prospecting for petroleum. A list of the mineral lands will be found on pages 24–31 of this report.

DEVILS DEN DISTRICT.

The tar springs in Little Tar Canyon in sec. 35, T. 23 S., R. 17 E.,[a] and near the north line of sec. 25, T. 25 S., R. 18 E., clearly indicate that the Vaqueros (lower Miocene) sandstone is the most likely reservoir for the accumulation of oil in this district. Oil or signs of oil are, in fact, not known to occur in any other formation within the district except, possibly, at the base of the shale of the Santa Margarita(?) formation. There remains, however, the possibility that the sands above the shales of the Santa Margarita(?) may be more or less impregnated by oil which may have its source in these shales, but as no indications of such an impregnation were discovered by the writers, the predictions are made and the land is classified on the assumption that the Vaqueros zone is the only petroliferous one available in this district.

[a] See report on the Coalinga oil district (Bull. U. S. Geol. Survey No. 398, p. 228).

The area offering the strongest inducements for prospecting in the Devils Den district lies northeast of the Vaqueros outcrop in sec. 24, T. 25 S., R. 18 E., and thence extends southeastward for a mile or more into sec. 30, T. 25 S., R. 19 E. The factors favoring this particular area are the occurrence of oil in the spring near the middle of the north line of sec. 25, T. 25 S., R. 18 E., and the favorable structural conditions offered by the curving of the formations immediately south and east of this point from a southeasterly to a southwesterly strike. It has been found elsewhere in the developed fields of California that wells located with reference to such structural conditions in petroliferous formations are usually good producers. Both northwestward and southeastward from this favorable territory the probabilities of obtaining oil in commercial quantities become less and less. This is indicated by the lack of direct evidence of petroleum in the outcrops of the Vaqueros sandstone. Westward from the territory outlined on the map as possibly productive, the formations are older than any which carry petroleum in commercial quantities in this district. Further negative evidence is afforded by the Spreckels wells, which penetrate the Cretaceous beds in the eastern part of T. 25 S., R. 17 E., and show no indications of petroleum. Eastward from the outlined territory the dip of the formations places the oil-bearing zone below the depth to which wells can now be profitably drilled.

LOST HILLS DISTRICT.

The area outlined as possibly productive of oil in the region of the Lost Hills is a continuation of a similar belt following the axis of the Coalinga anticline through the Kettleman Hills. The same arguments favoring the occurrence of petroleum in this anticline apply also with modifications to the region of the Lost Hills. The reader is referred to Bulletin 357, pages 120–124, for a discussion of the possibilities for obtaining petroleum in the Kettleman Hills.

The only direct evidence that hydrocarbons are contained in the formations underlying the Kettleman Hills is found at a place known as the Gas Bubble, in the SW. ¼ sec. 19, T. 26 S., R. 21 E., where certain shaly clays are impregnated with a dark-colored material having the odor of oxidized asphaltum. A considerable amount of a peculiar yellowish-orange gummy material was extracted by ether from the shales collected at this locality. It must be said, however, that the possibilities of the occurrence of petroleum in the Vaqueros sandstone underlying these hills appear to diminish as one passes from northwest to southeast, because, in the outcrop of the Vaqueros along Reef Ridge, Pyramid Hills, and the region of Devils Den, the impregnation of the sands is less and less southeastward. It is possible to calculate closely the depth below the surface at which the

Vaqueros sandstone lies in the Kettleman Hills, owing to the excellent outcrops of the overlying formations. In the Lost Hills, however, no outcrops, except beds of unknown age, occur, and for that reason it is impossible to determine with any degree of accuracy the depth of the Vaqueros sandstone below the surface. The general conditions, however, indicate that the axis of the Coalinga anticline is practically horizontal in the region of Light's place, north of Dudley, at the southeastern end of the Kettleman Hills, and it seems likely that this condition continues, with possibly slight variations, as far as the middle of the Lost Hills.

From the middle of the hills southeastward the topographic evidence indicates that the anticline plunges toward the southeast, and therefore it is thought likely that the Vaqueros sandstone in this direction soon reaches a depth unattainable by the drill.

BITTERWATER DISTRICT.

The Bitterwater district includes the Temblor Range south of Antelope Valley as far as Santos Creek, in the southeastern corner of T. 28 S., R. 19 E., as far westward as Palo Prieto Pass. A more or less detailed reconnaissance of this region by the writers failed to disclose any direct evidence of petroleum in the formations exposed. In the sandstone outcrop in the SE. ¼ sec. 6, T. 27 S., R. 19 E., and also in the exposures of the Vaqueros and Tejon formations in sec. 4, T. 28 S., R. 19 E., and at several other localities, the sandstone is stained peculiar reddish, yellowish, and orange tints, believed by some to suggest the former occurrence of petroleum in the beds, but tests of these discolored sands failed to disclose any indications of hydrocarbons. The structural conditions are ideal in portions of this region, and the shales of the Monterey and Santa Margarita (?) formations, which are believed to be the source of petroleum in the fields farther south, are present, but they are of a less purely diatomaceous character than in the region where they are known to yield oil.

TEMBLOR DISTRICT.

The Temblor district lies southeast of the Bitterwater district and northwest of the McKittrick district, and includes the northeastern flank of the Temblor Range and the outlying hills between Santos Creek in the southeastern corner of T. 28 S., R. 19 E., and a line passing westward from a short distance north of Frazer Spring into the head of the Santa Maria Valley in sec. 6, T. 30 S., R. 21 E., and thence northwestward to the crest of the range in sec. 33, T. 29 S., R. 20 E.

In addition to several productive wells in sec. 36, T. 29 S., R. 20 E., indications of petroleum are found in tar springs and asphalt deposits at several localities throughout the district. The most

important tar springs occur about one-half mile northeast of the Temblor ranch, in the northern part of sec. 36, T. 29 S., R. 20 E., and the southern part of sec. 25 in the same township. Brea deposits, consisting of shales and sands thoroughly saturated with asphaltum, occur in the northern part of sec. 12, T. 29 S., R. 20 E., in the NE. ¼ sec. 3, T. 29 S., R. 20 E., and in the SE. ¼ sec. 1 in the same township. Oil-impregnated diatomaceous shales overlain by favorable looking oil sand also occur in the E. ½ sec. 7, T. 29 S., R. 21 E. Wells said to have been moderately productive have been put down in the shales at this locality. An oil seepage is also said to occur about 2 miles north of the Temblor ranch, but this was not personally examined by the writers. From the positive evidence offered by the oil springs, brea outcrops, and wells it is quite evident that petroleum in commercial quantities is to be found in the Temblor district.

There are several areas in which the probabilities seem good for the future development of productive wells. One is the territory along the Temblor anticline east of the Temblor wells, in the northern part of sec. 36, T. 29 S., R. 20 E., as far as the broken-up territory in the eastern part of sec. 32, T. 29 S., R. 22 E. It is barely possible that even farther east along this anticline the conditions will be found such as to favorably reward prospecting with the drill, although the fracturing of the surface outcrops indicate rather uncertain conditions in the beds below. Another area along the south flank of the Temblor anticline and fault, south and west of the Temblor wells, also offers inducements for prospecting, especially where the beds have moderately low dips. In fact, it appears likely that the Vaqueros sand is oil bearing beneath practically all the shale area on both sides of the crest of the Temblor Range west and southwest of the Temblor ranch as far as Sandiego Canyon.

Still another locality offering inducements for prospecting is that lying northeast of the SE. ¼ sec. 7, T. 29 S., R. 21 E., as far as the line marking the 5,000-foot limit. The exposures of the tar sands, impregnated shales, and brea deposits and the structural conditions in this particular area all support the theory that commercial deposits of petroleum exist northeast of the oil-sand outcrops. Just how far northwest and southeast these favorable conditions extend is not known, but it seems likely that the McKittrick beds contain more or less petroleum all the way from the region opposite Carneros Spring southeastward to Buena Vista Lake. It is also possible that the beds even farther northwest than in front of Carneros Spring are impregnated. For that reason the line marking the supposed limit of the productive territory has been extended to the eastern part of T. 28 S., R. 19 E., although the probabilities lessen throughout this territory as one goes northwest from the Gould Hills.

The only territory in the district that does not offer inducements for prospecting is the Santa Maria Valley and the region northeast of the line shown on the map as marking the limits of the possible productive territory. The structural conditions in the Santa Maria Valley do not favor the accumulation of commercial quantities of oil, while in the region northeast of the line just mentioned the oil-bearing formations are believed to be more than 5,000 feet below the surface.

McKITTRICK DISTRICT.

The McKittrick district embraces the northeastern flank of the Temblor Range between a line drawn westward a short distance north of Frazer Valley and the central part of the E. ½ of T. 31 S., R. 22 E. It is bounded on the east by a north-south line which goes through McKittrick Pass and divides the Elk Hills from the McKittrick Valley and the hills northeast of it. A detailed study of the underground conditions in the McKittrick Valley leads to the conclusion that the McKittrick oil-bearing formation underlies practically all of the territory northeastward from the present line of productive wells. This line apparently marks the limit of the southwestward extension of the productive oil sands in the McKittrick formation, at least for some little distance. The Vaqueros oil zone undoubtedly underlies all of this territory, and is believed to be within reach of the drill over most of it, although at considerable depths. The test holes that have been put down in the McKittrick Valley and in the hills northeast of it indicate that the oil-bearing beds are not as productive in these lowlands as they are toward the southwest, but that commercial quantities of petroleum are available at reasonable depths. No thorough tests have been made on the northeastern flank of the northernmost anticline in the hills north of McKittrick, but judging by the results obtained by the wells within the hills it does not seem likely that exceptional producers will be obtained in any of the territory in question. An area believed to offer rather unusually favorable inducements for prospecting is that lying along the base of the hills and out into the McKittrick Valley between McKittrick and the Belgian (Temblor-McKittrick) Hills.

BUENA VISTA DISTRICT.

The Buena Vista district includes the region of the Elk Hills and Buena Vista Hills, and lies northwest of Buena Vista Lake, northeast of Midway Valley, and east and southeast of McKittrick Valley. The structural conditions in both the Elk and the Buena Vista hills are practically ideal for the accumulation of petroleum. As the shales of the Monterey and the Santa Margarita(?), which are believed

to be the source of the oil throughout this region, underlie the McKittrick beds that form the surface of the hills, the chances for obtaining commercial quantities of petroleum in the district are excellent. Assuming the thickness of the McKittrick formation to be about the same in the hills as it is in the Midway and McKittrick districts—that is, between 1,500 and 2,000 feet—it seems probable that at the axis of the Elk Hill anticline the oil-bearing zone is from 900 to 1,400 feet below the surface. As the edge of the hills is approached the dip of the beds carries the formations down, so that wells drilled near the edge would have to go at least 600 or 800 feet deeper than they would near the summit of the hills. Furthermore, the dip, at least on the southwest flank of the main anticline, steepens perceptibly toward the edge of the hills, and this would still further increase the depth to which the wells would have to be put down to penetrate the oil-bearing zone.

At least two of the test holes that have been drilled in the Buena Vista Hills have struck large quantities of gas in sands below thick clay deposits. As these wells are both near anticlinal axes the gas strikes indicate one of two things to the writers. Either the gas is the accumulation above oil that lies lower down the dip in the same stratum, or else the gas has been able to penetrate higher beds than could be penetrated by the oil from which it is believed to be derived, and the oil lies in the same formation as that containing the gas but in lower beds. In either case the occurrence of the gas is believed to be indicative of the presence of oil in the hills under discussion.

The arguments favoring the occurrence of petroleum in the Elk Hills are also applicable to the formations in the Buena Vista Hills, the anticlines apparently offering the strongest inducements because of the less depths at which the supposed oil-bearing formations would be encountered, and also because as a general rule the greatest accumulations of petroleum occur near the axes of anticlines.

A particularly advantageous locality for exploitation is that southeast of the region of the Belgian (now Temblor-McKittrick) wells in sec. 34, T. 30 S., R. 22 E. Not only are there indications of petroleum along the southeastward continuation of the Dabney anticline, but the dips on the flanks of this anticline support the theory that it is fractured little, if any, and therefore is more likely to retain its petroleum than it would be were it crushed and fractured. The flat country between the Buena Vista Hills and the hills southwest of the McKittrick Valley is covered by recent deposits which mask the underlying structure. It appears quite likely, however, that the anticlines which plunge southeastward under this masked area are continued in the anticlines found in the Buena Vista Hills, and in some instances this supposed relation has been shown on the map (Pl. I). Assuming therefore that the conditions are continuous across

these flats, it is almost certain that if petroleum is encountered on the flanks of these anticlines it will also be found beneath the flats along the continuation of the same anticline.

The only surface evidence of the occurrence of petroleum in Buena Vista Hills is the oxidized asphalt deposits in sec. 11, T. 32 S., R. 24 E. These occurrences strengthen the belief that commercial deposits of petroleum underlie the hills. In selecting points for development work the localities where the beds dip steeply should be avoided and those chosen where the dips are moderate and the conditions less favorable for faults and sharp flexures.

MIDWAY DISTRICT.

REGION WEST OF DEVELOPED MIDWAY FIELD.

In the Midway district petroleum occurs in all of the formations later than the Eocene. It is known to occur in commercial quantities in the McKittrick, for the Midway and Sunset fields secure their oil from the sands of this formation, and in favorable localities it will probably be found in commercial quantities in the Vaqueros sandstone, at the base of the Monterey shale, and in the Santa Margarita(?). The evidence on which this belief is founded is (*a*) the occurrence of oil in wells penetrating the Monterey and Vaqueros on the southwest flank of the range opposite Midway and on the northeast flank south of Crocker Spring, (*b*) the occurrence of oil in outcropping sands in the basal Monterey or upper Vaqueros at several localities in the canyons south and southwest of Crocker Spring, (*c*) the occurrence of indications of petroleum in the same zone along the entire northeast front of Temblor Range from Crocker Spring to the Sunset district, especially where the canyons cut the anticlinal axes, and (*d*) the locally favorable structural conditions throughout the region in which the evidences of oil occur. It is impossible in a report of this kind, based on a reconnaissance covering many hundreds of square miles, to go into details concerning the degree of probability of securing commercial quantities of petroleum in each quarter section. The most that can be said is that wherever it is calculated that the sands in the top of the Vaqueros formation or bottom of the Monterey can be reached at a depth of less than 5,000 feet from the surface, there the land is classified as mineral and the probabilities of encountering oil are believed to be worth considering. In a region of complex structure like that of the Temblor Range the conditions affecting the accumulation of oil differ widely within short distances, so that a detailed study of each particular locality is necessary before a proper conclusion can be drawn as to the depth of the oil-bearing zone below the surface. It may be said in general, however, that the most favorable localities are near the axes of the anticlines, especially those

with relatively low dipping flanks. Another favorable locality is along any line which marks a change from a low to a steep dip, both dips being in the same direction. This is simply a special form of the anticline in which the plane of the axis is oblique instead of vertical, as in a symmetrical anticline. An anticline which appears to fulfill these favorable conditions at one place or another along its course is the one lying one-half to 1 mile northeast of the crest of the range in the region southwest of the developed part of the Midway district. Other anticlines in the territory under discussion also appear favorable at one place or another, these particularly favorable localities usually being indicated on the map by anticlines with low dips. Another factor that must not be overlooked in calculating the probabilities of securing positive results at any particular point is the position in the formation of the beds exposed at the surface at the point in question. In the anticline mentioned above, which runs parallel with and not far from the crest of the range, the beds near the axis are usually close to or even practically coincident locally with the base of the Monterey, so that moderate depths should suffice to disclose the oil sands. Farther northeast and down the flank of the range the sands are buried deeper below the surface. In those localities where the dip of the strata is steep deep drilling will be necessary.

REGION NORTH AND NORTHWEST OF THE DEVELOPED TERRITORY.

The Midway Valley, locally known as the "Midway flats," offers reasonable inducements for exploitation. The hills southwest of the valley have indisputable evidence of their petroleum contents in the producing wells and outcrops of oil-bearing beds, while in the hills to the northeast there is also evidence indicating the petroliferous character of the underlying formations.

Two factors enter into the question of probability of obtaining productive wells in this valley. One is the question of the thinning toward the northeast of the coarse sand lenses which act as the reservoirs for the oil in the territory already tested; the other is the question whether or not water in the petroliferous zone will interfere with the successful operation of the wells. As to the first question, it seems likely that the coarser beds become thinner toward the northeast, but this thinning may be in part compensated for by the greater impregnation of the sands. The question of the control of the water is one that can be answered only after test holes are carefully put down. It has been the experience in analogous structural positions in other localities to find that the water in the beds increases toward the center of the syncline, and, as the Midway Valley is in a general way a great syncline, it is more than likely that the beds underlying it will be found to contain more water than the same beds nearer the edge of the valley.

Owing to the covering of the oil-bearing McKittrick formation by alluvial fans in the region northwest of the developed territory, it is impossible to predict the structural conditions with any degree of certainty. Evidence offered by the productive wells and the outcrops of the beds nearest the valley in the region north of the south line of T. 31 S. clearly indicates that the oil-bearing McKittrick formation continues northwest under the valley to the region east of the tank house, in sec. 17, T. 31 S., R. 22 E.

SUNSET DISTRICT.

REGION SOUTH AND SOUTHWEST OF THE DEVELOPED TERRITORY.

The region south and southwest of Sunset is occupied by a core of supposed Vaqueros (lower Miocene) sandstone along the axis of the Potts anticline, above this sandstone a thickness of 2,900 feet of siliceous and earthy Monterey shale, and still higher up the diatomaceous shale and intercalated sandstones of the Santa Margarita(?) formation. Several wells have been put down in this area, including the Manhattan near the center of sec. 11, T. 11 N., R. 24 W.; the Sunset Queen, near the middle of the east line of the NW. ¼ sec. 14, T. 11 N., R. 24 W.; the Potts well, in the southeast corner of sec. 23, T. 11 N., R. 24 W.; and the Sunset Petroleum and Refinery well, in the northwest corner of the NE. ¼ sec. 29, T. 11 N., R. 23 W. With the exception of the Sunset Queen, in which a little doubtful oil sand was reported, these wells struck no oil, but plenty of water. The Potts well is said to have been drilled to a depth of 1,361 feet and to have encountered water at 400 and 1,200 feet, the latter horizon yielding a flow of 40 to 50 barrels of salt water per day. The strata penetrated were hard quartz sands, with occasional thin layers of dark shale, the latter more abundant from 600 feet down. The other wells mentioned penetrated blue shale, with many hard streaks and occasional soft sands or water sands.

It is the opinion of the writers that this territory has not been thoroughly tested, and that the probabilities for finding oil in commercial quantities are good over certain areas in it. The oil is believed to be in the sands at the top of the Vaqueros and base of the Monterey; in other words, in the transition zone of alternating sandstone and shale between the two formations. The reasons for this belief are that seepages are found in this zone at several points along its line of outcrop in this particular territory; and, furthermore, that this is the horizon that yields the oil at the Smith and Erume wells, on the southwest flank of the Temblor Range opposite McKittrick. It is thought that the oil contained in the beds of this zone is lighter in gravity than that occurring in the McKittrick formation (Sunset oil sands), and even than that found in the same

formation as the last in the Midway district. The reasons for this belief are the quality of the oil found at the outcrop of the zone in the southern part of sec. 23, T. 11 N., R. 24 W., the quality of the oil found at the Erume wells at the same horizon, and the analogous position of the zone as regards the overlying siliceous diatomaceous shales (in which the oil is believed to originate) to certain of the oil sands of the Santa Maria district.

The areas best suited for testing the zone are those in which it would be struck at depths ranging from 600 to 1,200 feet and downward, and include strips on both sides of the Potts anticline. The width of these strips and their position relative to the axis of the anticline vary from point to point, depending on the dip of the beds. Some of these dips are shown on the map (Pl. I). In general, it may be said that the conditions are more favorable in those areas where the dip of the strata is least.

REGION EAST OF SUNSET.

The geologic conditions affecting the region along the base of the foothills and extending out into the flats east of the developed Sunset field indicate an indefinite eastward and southeastward extension of the field. The formations believed to be the source of the oil and also those acting as reservoirs for it undoubtedly underlie practically all of the region in question. Furthermore, evidence favoring its presence and conditions favoring its accumulation appear to be good. From a practical point of view the governing factor relating to its recovery appears to be the depth at which the deposits lie. The map (Pl. IV), indicating the position of the top of the oil-bearing zone by contours, furnishes the desired data for the developed portion of the field and the territory immediately adjacent. The flats east of the contoured area are affected by two lines of structure, the north-northeast dipping monocline flanking the foothills of the Mount Pinos Range, and the Thirty-five anticline, which passes slightly south of east into the flats from the southern part of sec. 35, T. 12 N., R. 24 W. From the available data at hand it is believed that the axis of the last-mentioned anticline plunges east with a dip less than 12°. This would carry the top of the oil zone (zone B) to a depth of 5,000 feet below the surface at the top of the anticline on the northern part of sec. 10, T. 11 N., R. 23 W., as shown on the map (Pl. I). The prospects for productive wells are believed to be good along this anticline at least as far out on the flat as the point just mentioned, and possibly farther, for the dips tend to lessen as the beds approach the valley. It is therefore possible that the productive zone is actually wider than is indicated by calculations based on dips taken near the hills. The sharp upturning of the beds in secs. 17 and 18, T. 11 N., R. 23 W., and southeast

of the latter, indicate a narrowing of the possible productive territory north of these sections. The theoretical location of the Phœnix syncline, which marks the lowest portion of the productive beds between the hills on the south and the Thirty-five anticline on the north, has been calculated from all available data and located as shown on the map (Pl. I). In general it may be said that difficulties with water will increase with approach to the axis of the syncline; furthermore, it is believed that the productiveness of the wells will be found to decrease eastward from the vicinity of Hazelton, at least for about 3 miles.

CARRIZO PLAIN DISTRICT.

The Carrizo Plain district includes the region southwest of Palo Prieta Pass as far as the southeast corner of T. 28 S., R. 18 E., and the region southwest of the crest of the Diablo Range southeastward from the same corner. It embraces the Carrizo and Elkhorn Plains, the northeastern flank of the Caliente Mountains, and the fringe of hills along the southwestern edge of the Carrizo Plain. A very hasty reconnaissance of the hills southwest of the Carrizo Plain as far south as Painted Rock ranch, in sec. 30, T. 31 S., R. 20 E., discloses evidence of petroleum at only one point. This was in the northern part of sec. 23, and the southern part of sec. 14, T. 29 S., R. 17 E., where an oil sand outcrops at the base of the Santa Margarita (?) formation. The sand here was not over 10 feet thick, consisted of coarse quartz grains, and showed a tendency toward concretionary structure. It immediately overlies the Monterey shale, which outcrops in the axis of an anticline passing through the locality mentioned. This occurrence of oil sand indicates that petroleum in small amounts occurs at the base of the Santa Margarita (?) formation throughout at least a portion of the Carrizo Plain region, north of the southern part of T. 29 S., R. 18 E.

It is not thought probable that deposits of economic importance will be encountered in this region, as the structural conditions are more or less unfavorable owing to the numerous faults that affect the formations adjacent to the plain. No other indications of petroleum were found on the southwestern flanks of Temblor Range north of an east-west line through the mouth of Sandiego Canyon. Numerous indications of petroleum are found in the Vaqueros and overlying formations southeast of Sandiego Canyon, along the flanks of the Temblor Range, and it appears highly probable that commercial deposits of petroleum occur at many places along the anticlines in this region. The anticline which begins about half a mile south of Sandiego Joe's—that is, at the southeast corner of sec. 8, T. 30 S., R. 20 E.—and passes southeastward along the flanks of the range (see map, Pl. I) has been tested at two different localities over a mile apart, at the

Smith wells near the corner of secs. 22, 23, 26, and 27, T. 30 S., R. 20 E., and a mile northwest of that point.

The Vaqueros also yields oil near the surface at the Erume wells in the southern part of sec. 22, T. 31 S., R. 21 E. The peculiar pinkish color indicative of petroleum is also found at practically all the outcrops of the Vaqueros in the anticlines along this part of the range.

Bearing in mind these favorable indications, it appears probable that wells sunk through the overlying Monterey shale and tapping the Vaqueros sandstone at advantageous localities will yield petroleum. As the petroleum produced by the shallow holes so far sunk is particularly good, ranging as high as 28° Baumé, it seems probable that oil wherever obtained from the Vaqueros will be excellent. As the conditions here mentioned as favorable continue practically uninterrupted along the range as far southeast as the region back of Sunset, it seems likely that prospecting in favorable localities in the Carrizo Plain district should secure positive results. Owing to the complex folding and accompanying faulting which affects this region, even to a greater extent than the northeastern flank of the range, detailed examinations of any particular area should be made before predictions are attempted. On the accompanying map (Pl. I) the principal lines of structure are indicated. It is thought by the writers that the anticlines with low-dipping flanks offer the best inducements for exploitation.

PRODUCTION.

The following table of production of the McKittrick, Midway, and Sunset fields by calendar years from 1900 to 1908 was compiled by Miss Belle Hill, under the direction of Dr. David T. Day, of the United States Geological Survey:

Barrels of oil produced in McKittrick, Midway, and Sunset fields, California, 1900–1908.

Year.	McKittrick.	Midway.	Sunset.	Total.
1900				892,500
1901	430,450	4,235	188,600	623,285
1902	619,296	3,048	[a] 167,558	789,902
1903	658,351	[a] 5,000	[a] 250,000	913,351
1904				
1905	276,171	11,033	302,701	588,905
1906	531,185		409,335	940,520
1907	1,944,671	134,174	567,175	2,646,020
1908	2,517,951	410,393	1,556,263	4,484,607

[a] Estimated.

STORAGE.

The storage facilities of the McKittrick field consist of three 55,000-barrel tanks, in addition to a dozen or more earthen settling and temporary storing reservoirs and several small settling and temporary storing tanks.

The storage capacity of the Midway field is practically limited to the tanks of the Standard Oil Company, at their pumping plant in the edge of the Buena Vista Hills.

The storage facilities in the Sunset field consist largely of open earthen reservoirs. Two covered earthen reservoirs, with a total storage capacity of about 100,000 barrels, and four or five metal tanks holding all told about 150,000 barrels, comprise the remainder of the storage room.

TRANSPORTATION.

Two railroads and one pipe line carry oil from the McKittrick-Sunset region, and two other pipe lines to accommodate the same territory are now in course of construction. A branch of the Southern Pacific Railroad joins McKittrick and Olig with the main lines of the Southern Pacific Company and the Atchison, Topeka and Santa Fe Railway at Bakersfield, while the Sunset Western Railroad, owned jointly by the Southern Pacific Company and the Atchison, Topeka and Santa Fe Railway, joins Midoil, Moron, Monarch, and Hazelton with the same roads at the same junction. Most of the oil in the McKittrick and Sunset fields and a part of the product of the Midway field is carried in tank cars on these branch lines. An 8-inch pipe line of the Standard Oil Company joins Bakersfield and the pump station on the edge of the Buena Vista Hills in sec. 1, T. 32 S., R. 23 E. Branch lines run from this station to the McKittrick and Midway fields. The Producers Transportation Company now has in course of construction an 8-inch line joining the Sunset, Midway, and McKittrick fields with Port Harford. This line is joined by a similar one from Coalinga at the Antelope Valley station, and a branch from McKittrick runs to the Kern River field, near Bakersfield. The Associated Oil Company is also constructing a pipe line from Sunset through the Midway, McKittrick, and Coalinga fields to its main Kern River and Port Costa line at Mendota.

SURVEY PUBLICATIONS ON PETROLEUM AND NATURAL GAS.

The following list includes the more important papers relative to oil and gas published by the United States Geological Survey or by members of its staff. The United States publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Certain of the geologic folios also contain references to oil, gas, and asphaltum.

Adams, G. I. Oil and gas fields of the western interior and northern Texas coal measures and of the Upper Cretaceous and Tertiary of the western Gulf coast. In Bulletin No. 184, pp. 1–64. 1901.

Adams, G. I., Haworth, E., and Crane, W. R. Economic geology of the Iola quadrangle, Kansas. Bulletin No. 238. 83 pp. 1904.

Anderson, R. Geology and oil prospects of the Reno region, Nevada. In Bulletin No. 381.

——— Two areas of oil prospecting in Lyon County, western Nevada. In Bulletin No. 381.

——— (See also Arnold, R., and Anderson, R.)

Arnold, R. The Salt Lake oil field, near Los Angeles, Cal. In Bulletin No. 285, pp. 357–361. 1906.

——— Geology and oil resources of the Summerland district, Santa Barbara County, Cal. Bulletin No. 321. 67 pp. 1907.

——— (See also Eldridge, G. H., and Arnold, R.)

——— The Miner ranch oil field, Contra Costa County, Cal. In Bulletin No. 340, pp. 339–342. 1908.

Arnold, R., and Anderson, R. Preliminary report on the Santa Maria oil district, Santa Barbara County, Cal. Bulletin No. 317. 69 pp. 1907. 15c.

——— ——— Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal. Bulletin No. 322. 124 pp. 1907. 50c.

——— ——— Preliminary report on the Coalinga oil district, Fresno and Kings counties, Cal. Bulletin No. 357. 142 pp. 1908.

——— ——— Geology and oil resources of the Coalinga district, Cal. Bulletin No. 398. 354 pp. 1910.

Becker, G. F. Relations between local magnetic disturbances and the genesis of petroleum. Bulletin No. 401. 24 pp. 1909.

Boutwell, J. M. Oil and asphalt prospects in Salt Lake basin, Utah. In Bulletin No. 260, pp. 468–479. 1905. 40c.

Clapp, F. G. The Nineveh and Gordon oil sands in western Greene County, Pa. In Bulletin No. 285, pp. 362–366. 1906.

——— (See also Stone, R. W., and Clapp, F. G.)

Cram, M. P. (See Gilpin, J. E., and Cram, M. P.)

Crane, W. R. (See Adams, G. I., Haworth, E., and Crane, W. R.)

Darton, N. H. Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming. Professional Paper No. 65. 1909.

DAY, D. T. Petroleum. In Mineral Resources U. S. for 1907, pt. 2, pp. 347–475. 1908.

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——— Analyses of crude petroleum from Oklahoma and Kansas. In Bulletin No. 381.

——— The petroleum resources of the United States. In Bulletin No. 394, pp. 30–50. 1909.

——— Natural-gas resources of the United States. In Bulletin No. 394, pp. 51–61. 1909.

ELDRIDGE, G. H. The Florence oil field, Colorado. In Trans. Am. Inst. Min. Eng., vol. 20, pp. 442–462. 1892.

——— The petroleum fields of California. In Bulletin No. 213, pp. 306, 321. 1903. 25c.

ELDRIDGE, G. H., and ARNOLD, R. The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California. Bulletin No. 309. 266 pp. 1907. 80c.

FENNEMAN, N. M. The Boulder, Colo., oil field. In Bulletin No. 213, pp. 322–332. 1903. 25c.

——— Structure of the Boulder oil field, Colorado, with records for the year 1903. In Bulletin No. 225, pp. 383–391. 1904. 35c.

——— The Florence, Colo., oil field. In Bulletin No. 260, pp. 436–440. 1905. 40c.

——— Oil fields of the Texas-Louisiana Gulf coast. In Bulletin No. 260, pp. 459–467. 1905. 40c.

——— Oil fields of the Texas-Louisiana Gulf coastal plain. Bulletin No. 282. 146 pp. 1906.

FULLER, M. L. The Gaines oil field in northern Pennsylvania. In Twenty-second Ann. Rept., pt. 3, pp. 573–627. 1902.

——— Asphalt, oil, and gas in southwestern Indiana. In Bulletin No. 213, pp. 333–335. 1903. 25c.

——— The Hyner gas pool, Clinton County, Pa. In Bulletin No. 225, pp. 392–395. 1904. 35c.

GALE, H. S. Geology of the Rangely oil district, Rio Blanco County, Colo., with a section on the water supply. Bulletin No. 350. 1908.

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——— Structural work during 1901-2 in the eastern Ohio oil fields. In Bulletin No. 213, pp. 336–344. 1903. 25c.

——— Petroleum. In Mineral Resources U. S. for 1906, pp. 827–896. 1907.

——— Structure of the Berea oil sand in the Flushing quadrangle, Ohio. (In preparation.)

GRISWOLD, W. T., and MUNN, M. J. Geology of oil and gas fields in Steubenville, Burgettstown, and Claysville quadrangles, Ohio, West Virginia, and Pennsylvania. Bulletin No. 318. 196 pp. 1907. 75c.

HAWORTH, E. (See Adams, G. I., Haworth, E., and Crane, W. R.; also Schrader, F. C., and Haworth, E.)

HAYES, C. W. Oil fields of the Texas-Louisiana Gulf coastal plain. In Bulletin No. 213, pp. 345–352. 1903. 25c.

HAYES, C. W., and KENNEDY, W. Oil fields of the Texas-Louisiana Gulf coastal plain. Bulletin No. 212. 174 pp. 1903. 20c.

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KENNEDY, W. (See Hayes, C. W., and Kennedy, W.)

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——— (See also Phinney, A. J.)

MUNN, M. J. (See Griswold, W. T., and Munn, M. J.)

——— Geology of the oil and gas fields of the Sewickley quadrangle, Pennsylvania. Topographic and Geologic Survey Commission of Pennsylvania. (In press.)

——— Geology of the oil and gas fields of the Clarion quadrangle, Pennsylvania. Topographic and Geologic Commission of Pennsylvania. (In press.)

——— Petroleum and natural gas, in Report of progress on geologic works under the Topographic and Geologic Survey Commission of Pennsylvania.

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——— Petroleum. In Mineral Resources U. S. for 1903, pp. 635–718. 1904. Idem for 1904, pp. 675–759. 1905.

——— Natural gas. In Mineral Resources U. S. for 1903, pp. 719–743. 1904. Idem for 1904, pp. 761–788. 1905.

ORTON, E. The Trenton limestone as a source of petroleum and inflammable gas in Ohio and Indiana. In Eighth Ann. Rept., pt. 2, pp. 475–662. 1889.

PHINNEY, A. J. The natural gas field of Indiana, with an introduction by W J McGee on rock gas and related bitumens. In Eleventh Ann. Rept., pt. 1, pp. 579–742. 1891.

REED, W. J. (See Taff, J. A., and Reed, W. J.)

RICHARDSON, G. B. Natural gas near Salt Lake City, Utah. In Bulletin No. 260, pp. 480–483. 1905.

——— Salt, gypsum, and petroleum in trans-Pecos Texas. In Bulletin No. 260, pp. 573–585. 1905.

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DEPARTMENT OF THE INTERIOR

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BULLETIN 407

GEOLOGY AND ORE DEPOSITS

OF THE

BULLFROG DISTRICT, NEVADA

BY

F. L. RANSOME, W. H. EMMONS

AND G. H. GARREY

WASHINGTON

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ILLUSTRATIONS.

GEOLOGY AND ORE DEPOSITS OF THE BULLFROG DISTRICT, NEVADA.

By Frederick Leslie Ransome, William H. Emmons, and George H. Garrey.

INTRODUCTION.

By F. L. Ransome.

SITUATION AND ACCESS.

The name "Bullfrog district" is usually rather vaguely applied to a large tract of desert hills and mountains extending far to the north and west of the area here particularly described. For convenience, however, the name as used in this report will refer as a rule to the area mapped in Plate I, although account will be taken of a few mines and some scattered prospects lying short distances beyond its boundaries.

The position of the district is shown on the index map (fig. 1). Rhyolite, the principal town, lies 60 miles south-southeast of Goldfield, with which it is connected by the Las Vegas and Tonopah Railroad (73.5 miles) and the Bullfrog Goldfield Railroad (81 miles). To the south there is connection with Las Vegas, Nev., on the San Pedro, Los Angeles and Salt Lake Railroad, over the Las Vegas and Tonopah Railroad, a distance of 123.5 miles, and with Ludlow, Cal., on the Atchison, Topeka and Santa Fe Railway, over the Tonopah and Tidewater Railroad, 171 miles in length. The town of Rhyolite is situated at the south base of a short east-west range of hills that connects the Grapevine Mountains on the west with Bare Mountain and other irregular groups of peaks, ridges, and mesas on the east, and separates the Amargosa Desert on the south from a similar desert basin that extends north past Stonewall Mountain toward Goldfield.

The other towns in the district are Bullfrog, which adjoins Rhyolite on the south, and Beatty, 4 miles east of Rhyolite, on the so-called Amargosa River, a feeble rill of water that is fed by springs a few miles north of the town and is finally absorbed in the sand and gravel of the Amargosa Desert.

FIELD WORK AND AUTHORSHIP.

In the autumn of 1905 a topographic map of the most important part of the Bullfrog district, covering an area 7.25 miles from east to west and 2.9 miles from north to south, was made by Mr. William Stranahan, topographer, on the scale of 1:24,000, with contour intervals of 20 feet. This map shows the town of Beatty near its eastern margin and includes the Original Bullfrog mine on the west. Geo-

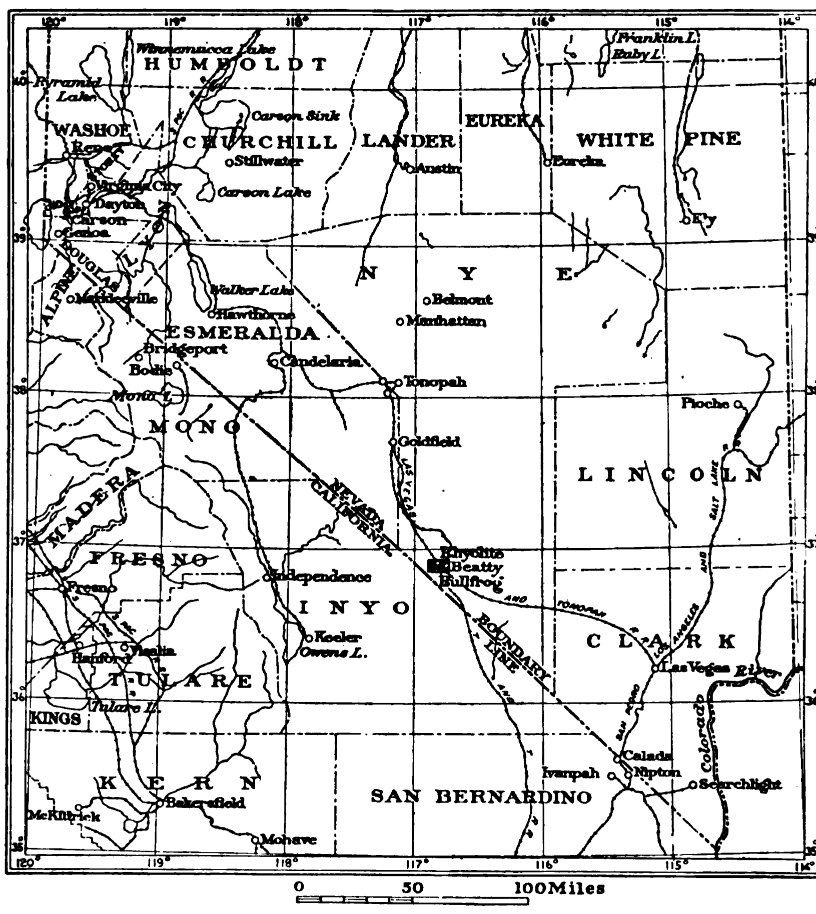


FIGURE 1.—Index map showing position of the Bullfrog district.

logic work was begun in December of the same year and carried on until March, 1906. Messrs. W. H. Emmons and G. H. Garrey mapped the rocks and studied in detail their relations and character. while Mr. F. L. Ransome devoted a shorter time to a general survey of the field and to the examination of the ore deposits.

In consequence of a change in the boundaries of the topographic map prior to the final engraving of the plate, Mr. Emmons revisited

the district for a few weeks in January and February, 1907, and mapped geologically such additional area as was required by the modification of the original topographic base. Finally, in the summer of 1908, Mr. Ransome spent a week in the district studying mine workings opened since March, 1906.

The study of the general geology was carried out jointly by Messrs. Emmons and Garrey under the direct supervision of Mr. Ransome.

LITERATURE.

The Bullfrog Hills, lying aside from the routes followed by the transcontinental railways and being inconspicuous features in comparison with the loftier ranges and remarkable valleys of the Great Basin, appear not to have attracted the attention of the earlier geologic explorers in Nevada. The following list of publications dealing with the region is accordingly short, and those that appeared before the year 1906 deal merely with the region as a whole. Brief articles in the mining press have contributed at various times information regarding mining and milling progress, but these are not here listed, since they afford no important geologic information and are not of lasting interest:

GILBERT, G. K. Report on the geology of portions of Nevada, Utah, California, and Arizona; examined in the years 1871 and 1872: U. S. Geog. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 32–33.

Gives a diagram showing the structure of the west face of Bare Mountain southeast of the Bullfrog district, with brief notes. Estimates that not less than 8,000 feet of bedded rocks is exposed.

SPURR, J. E. Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: Bull. U. S. Geol. Survey No. 208, 1903. (Second edition in 1905.)

The route of this reconnaissance was north and west of the Bullfrog Hills. A general geologic map of this part of Nevada and California, "compiled from all available information," on a scale of 15 miles to the inch, accompanies this report. The area occupied by the Bullfrog Hills is shown as "fine-grained igneous rocks," and the same color is extended over Bare Mountain.

BALL, SYDNEY H. Notes on ore deposits of southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 285, 1906, pp. 53–73.

An advance report on part of the material embodied in the following publication.

BALL, SYDNEY H. A geological reconnaissance in southeastern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, pp. 176–182.

Describes the general geology of the Bullfrog Hills and adjacent region. A geologic reconnaissance map on a scale of 1 : 250,000 (approximately 4 miles to the inch), covering 8,550 square miles, accompanies this report.

KRUMB, HENRY. Report on the Montgomery-Shoshone Consolidated Mining Company, New York, 1908.

The report deals particularly with the ore reserves, but contains some geologic data.

RANSOME, F. L. A preliminary account of Goldfield, Bullfrog, and other m
districts in southern Nevada; with notes on the Manhattan district by
Emmons and G. H. Garrey: Bull. U. S. Geol. Survey No. 303, 1906.
An advance report superseded as regards the Bullfrog district by the p
publication.

EMMONS, W. H. Normal faulting in the Bullfrog district: Science, n. ser., v
1907, pp. 221-222.
A brief discussion of the mechanics of the faulting.

HISTORY OF MINING DEVELOPMENT.

Long prior to the discoveries at Tonopah and Goldfield the sp in Oasis Valley, just north of the site of Beatty, proved attracti a few wanderers, who established rude ranches along Amar River, the only stream of drinkable water within a radius o miles. Occasionally prospectors traveling northeastward from D Valley or northwestward from the springs at Ash Meadow would the night at one of these ranches, perhaps spend a few days exa ing the hills in the neighborhood, and then again set out over desert plains.

The remarkable development of Tonopah and the finding of ore at Goldfield stimulated prospecting throughout all of so western Nevada, and the rapid advance of the material adjunc civilization into this most inhospitable region greatly lessened hardship and danger that had hitherto attended a traveler far bases of supply and vitally dependent upon scattered and e missed springs. In the autumn of 1904 the Bullfrog claim located on a prominent outcrop of quartz (see Pl. I), about 3 m west of the site of Rhyolite. The name, which afterward bec that of the district, is said to have been suggested by the green c of the ore, and the ironical humor that associated it with a plac scorching aridity is characteristic of the Nevada pioneers.

The usual rush of prospectors followed the first discovery, most of the ground between the Bullfrog claim and Amargosa Ri was soon covered with claims. A settlement of tents, known Amargosa City, sprang up near the Bullfrog claim, but when center of interest shifted eastward to Bonanza and Ladd mounta the first town was abandoned for the settlements of Bonanza, B frog, and Beatty. In February, 1905, a town-site company l out the streets of Rhyolite and, by offering a certain number of l free, succeeded in a few days in establishing this as the chief town the district.

Up to the latter part of the year 1906 owners of claims were occ pied chiefly in the development of their properties, it being imprac cable to ship any but the richest ore under the conditions of tran portation then prevailing; moreover, the most important mine, t Montgomery-Shoshone, was involved in litigation, which acted

an additional check on production. In the latter part of 1906 the Las Vegas and Tonopah Railroad reached the district, and by the middle of 1907 the Bullfrog Goldfield Railroad had been completed. Before the end of the year the Tonopah and Tidewater Railroad and the extension of the Las Vegas and Tonopah Railroad to Goldfield were in operation. Thus in a little over a year the new camp passed from desert isolation into the enjoyment of railway facilities superior to those of many long-established and highly productive districts.

With the completion of the railways the Bullfrog district began the shipment of ore and by the end of November, 1907, the Montgomery-Shoshone mine was producing ore and concentrates at the rate of about $150,000 a month, gross value. This fell off about half in the summer of 1908.

PRODUCTION.

Up to the end of the year 1906, as already stated, work in the district was confined mainly to prospecting and to blocking out ore. Prior to the beginning of that year the Montgomery-Shoshone, it is said, shipped about 100 tons of rich ore, the Original Bullfrog about 13 tons, and the Denver about 1,000 sacks. Small shipments were made in 1906 also from the Montgomery-Shoshone, Skookum-Bullfrog, Gibraltar, and Tramps groups of mines, but the amount is not recorded. During 1907 the production was 9,050 tons of ore, containing $132,428 in gold, $74,991 in silver, $112 in copper, and $7 in lead, a total of $207,538.[a]

TOPOGRAPHY.

The Bullfrog Hills (Pl. II) attain a maximum elevation of 6,095 feet above the sea, the highest point being about a mile beyond the northern boundary of the area covered by the detailed map. The hills, which are steep, rocky, and practically bare of vegetation, rise sharply from the gently sloping desolate plains that border them on the north and south. The marginal elevation of these plains ranges from about 3,300 feet on Amargosa River at Beatty to about 4,500 feet at Mud Spring, 4 miles north of Rhyolite, and the local relief of the hills is thus about 2,800 feet. Southeast of Beatty, Bare Mountain, which culminates in a peak 6,235 feet high, presents a steep southwest front to the Amargosa Desert and an eastern face almost as precipitous to an embayment of the same plain. On the north, however, the mountain, which is composed principally of schist, limestone, and quartzite, merges into hills (see Pl. II) which, in spite of the topographic break due to the Oasis Valley, are structurally and lithologically an eastern continuation of the Bullfrog Hills. To the

[a] Mineral Resources U. S. for 1907, pt. 1, U. S. Geol. Survey, 1908, p. 372.

west the Bullfrog Hills extend without any definite topographic or geologic break into the Grapevine Mountains.

The hills in the area particularly described in this report constitute a very irregular group, partly buried by the thick stony alluvium characteristic of the broad, undrained basins of arid Nevada. The upper limit of the alluvium, unlike that at Goldfield, is remarkably definite, and above it the rocky structure of the hills is laid bare to a degree highly satisfactory to the geologist. A view over the district from any commanding summit suggests at once that the region owes its main features to the cooperation of faulting and erosion acting on a thick series of lavas. Many of the ridges are obviously fault blocks, most of them tilted to the east, so that their western scarps show the horizontal banding of successive flows (see Pl. III), while their northeast faces exhibit merely the irregular pinnacles and ravines characteristic of the erosion of a dip slope of a single rock layer of generally homogeneous texture. Moreover, the individual white, gray, green, pink, brown, or black bands that represent the edges of different flows can never be traced far before they are sharply offset or cut off entirely in a manner that can be due only to faulting. The faults, accordingly, are not parallel but intersect one another, and it is evident that the irregularity of relief and the absence of continuous lines of parallel ridges and valleys are the visible expression of a complexly faulted structure. How far this expression is direct and how far it has been modified or transformed by erosion will be considered in another place. There are no perennial streams in the district except Amargosa River, but erosion, though fitful in its activity, proceeds at times with great energy, and the water that falls upon the hills undoubtedly accomplishes more erosive work than would the same quantity under the conditions prevailing in a humid country well covered with vegetation. The arid, stony slopes of the Bullfrog Hills (see Pl. II) are elaborately carved by running water, and Box Canyon, a mile west of Rhyolite, is striking testimony to the power of a stream that is probably active for only a few hours or a few days in the year.

PRELIMINARY OUTLINE OF THE GEOLOGY AND ORE DEPOSITS.

The prevailing rocks of the area studied—the ones that give character to the topography and that contain the ore deposits—are rhyolitic flows of Tertiary age. Much older rocks, however, are exposed in the southwestern and southeastern parts of the district. These constitute a crystalline complex of quartz-biotite and quartz-muscovite schists, quartzite and quartz schist, marble, and injection gneisses, the last-named inclosing small masses of schistose greenstone derived from rocks originally of dioritic character. The complex as a whole represents ancient sediments (sandstones, shales, and limestones),

A. RAINBOW MOUNTAIN FROM THE HOBO SHAFT ON BONANZA MOUNTAIN.

The highest point is Black Peak, capped with quartz latite. The Montgomery-Shoshone mine is in the saddle to the right.

B. VIEW TO THE EAST FROM THE MONTGOMERY-SHOSHONE MINE.

On the left is Burton Mountain, in which rhyolites Nos. 11, 12, and 13 are repeated by a strike fault. The high hills to the right are part of Bare Mountain.

which have been crumpled and kneaded under high pressure and temperature in the zone of rock flowage. Remnants of a much less metamorphosed limestone, probably of Silurian age, rest in some places on the schist.

Probably more than one period of erosion was required to lay bare these once deeply buried schists. It is fairly safe to conclude that at the close of the extensive denudation to which western Nevada was subjected during Cretaceous time these schistose rocks with areas of the overlying Paleozoic limestone formed part of the worn surface over which the earliest Tertiary lavas spread. Although the schists now exposed in the district are found only in fault contact with the Tertiary rocks, there is little question that they are the fundamental terrane of the region and that, with some locally intervening Paleozoic limestone, they underlie the volcanic series of the Bullfrog district.

The Tertiary rocks, which have an aggregate thickness of at least 6,000 feet, cover most of the area and contain all the known ore bodies of importance. The greater part of the series is rhyolite, and sixteen successive formations of this rock have been recognized and mapped by Messrs. Emmons and Garrey. These formations are not necessarily individual flows. Some of them are really parts of a single thick flow, and others are certainly composed of several flows. Intercalated between the rhyolites are five flows of plagioclase basalt, one flow of quartz latite, some stratified tuffs, and finally, capping the series, a flow of quartz-bearing basalt. The effusive rocks are cut by intrusions of rhyolitic porphyry, plagioclase basalt, and leucite basanite. Most of the basalt dikes occupy fault fissures.

The Tertiary lavas and tuffs are generally conformable to one another, but at a few places slight erosional unconformity has been detected.

The entire series of volcanic rocks is divided by faults into a large number of blocks in each of which the flows are in general tilted to the east at angles up to 40°. The fault planes strike from northwest to northeast and dip generally to the west. The displacement, as a rule, is normal; that is, the hanging wall in each case has slipped down relatively to the foot wall. In consequence of this structure anyone traveling across the district from west to east will see the edges of the same flows repeated again and again in the successive western fronts of the ridges. To the production of this structure two types of deformation have contributed, according to Messrs. Emmons and Garrey. (See p. 82.) These were (1) a general tilting toward the east, such as would result from the development of a broad arch or monocline of which the eastern limb coincided with the Bullfrog district; and (2) step faulting with progressive downthrow to the west. The two processes were simultaneous and compensatory.

Their cooperation tended to minimize the actual vertical displacement of the flows from their original nearly horizontal position.

In that part of the district between Sawtooth Peak and Beatty the angle at which the flows are tilted is such as to carry them down toward the east more rapidly than they are brought up by the successive step faults. Consequently some of the older flows are here concealed and younger flows, not present in the western part of the district, make their appearance. East of Beatty, however, a fault of very great throw brings to the present surface the oldest of the rhyolite flows.

In addition to the dominant faults just referred to, there is another and possibly in part younger set, characterized by nearly northeast-southwest trends. In general the throws of the northeast faults are less than those of the north or northwest faults, but a few northeast faults show profound displacement. The northeast faults are particularly noticeable on the geologic map (Pl. I), owing to the manner in which they offset the outcropping edges of the various flows. The structural importance of the north to northwest faults is somewhat masked by the facts that they are in some cases partly or wholly covered by alluvium and are less numerous than those of the other system. The structure (see Pl. I) shows that under the band of alluvium between Bullfrog Mountain and Box Canyon must lie concealed one of the greatest faults in the district. Another important dislocation must be covered by the alluvium between Ladd and Montgomery mountains.

Most of the faults dip at high angles, but there are apparently two notable exceptions to this rule. The contact between the rhyolites and the pre-Tertiary rocks in the vicinity of the Original Bullfrog mine dips to the north at an angle of 18° to 20°. It is not well exposed but seems to be a plane of great disturbance. The various rhyolitic formations of Bullfrog Mountain dip to the east at considerable angles and are successively cut off at this contact. (See Pls. I and IX, *A*.) It is difficult to understand how normal faulting could take place on a plane so slightly inclined unless the displacement had a large horizontal component.

South of Beatty the relation of the Tertiary volcanic rocks to the pre-Tertiary metamorphic rocks is similar to that just described. The contact is probably a fault, although the actual exposures of it are not as satisfactory as could be desired. East of Beatty, however, the rhyolites are clearly faulted down against the limestones and quartzites of Bare Mountain. The fault here dips northward at angles between 50° and 65° and the rocks adjacent to the fissure are crushed.

In general, the rhyolites of the Bullfrog Hills appear to be bounded on the south by a nearly east-west fault or fault zone, which appar-

ently has dropped them against a pre-Tertiary metamorphic terrane, forming the mass of Bare Mountain and exposed in a few low hills along the northern edge of the Amargosa Desert. The entire volcanic mass has been divided by other faults into numerous small blocks.

Many of the faults are accompanied by basaltic dikes. In some cases the dike fills the fault fissure and is not itself disturbed. In other cases the faulting is in part later than the intrusion, so that the dike has been fractured or crushed by the movement. A very common feature of these dikes is their lack of continuity, the basalt occurring here and there along a persistent fissure. This peculiarity is probably in part due to movements subsequent to the intrusion, but along many of the fissures the basalt appears to have been intruded only at intervals.

At no one place in the district is a complete section of the Tertiary lavas shown. This is not due to lack of exposures, but to the close spacing of the faults by which the country is dissected into blocks. Each flow or bed is, as a rule, exposed in two or more blocks, and since these partial sections can be correlated, it is possible by piecing them together to effect a restoration of the whole.

The deformation of the series by tilting and faulting was followed by extensive erosion, which sculptured the rocks into their present forms and has supplied the abundant débris now filling the valleys.

The ore deposits are for the most part nearly vertical mineralized faults or fault zones in rhyolite. Of the many faults shown in Plate I comparatively few have proved ore bearing, although it must be remembered that the district is undeveloped and that a number of the faults discovered in the course of the geologic mapping have not yet attracted the attention of prospectors. The presence or absence of mineralization bears no evident relation to the particular variety of rhyolite constituting the country rock and does not appear to be proportional to the degree of dislocation along the fissures, but apparently is governed mainly by locality. No ore is known, however, in any formation younger than rhyolite No. 12.

Most of the lodes are not simple veins, but are fissure zones containing numerous veinlets or stringers of vein material and in most cases showing no definite walls. The principal stringers are parallel with the sides of the lode as a whole, but they are linked by numerous irregular cross veinlets, and similar small stringers extend for varying distances into the country rock. The lodes range in width from a few inches to 10 or even 100 feet.

Originally the veinlets consisted of quartz and calcite carrying finely disseminated auriferous pyrite. The calcite, possibly associated in some places with other carbonates, varies in abundance. The larger stringers, such as those of the Hobo vein, at many places

exhibit regular depositional banding or crustification. Many of the stringers are distinct fissure fillings, with a definite contact between them and their rhyolite walls. Examples of transition from vein filling to country rock, due to the silicification of the latter, are by no means lacking, however, although this process has not been carried to anything like the extent observable at Goldfield. Much of the quartz, including some good ore, has a fine granular texture and has in part been formed by the silicification of shattered or crushed rhyolite. Typical vein quartz, such as is characteristic of the gold veins of the Appalachians or Sierra Nevada or such as is found in the pre-Tertiary schists of the Bullfrog district, does not occur in the mines near Rhyolite, with the exception of the Original Bullfrog. The quartz is prevailingly fine grained, often of a porcelain-like texture, and is usually intercrystallized with calcite.

In the process of oxidation, which in most of the lodes has been facilitated by movements that have fissured or shattered the original filling, the crystals of pyrite are changed to specks of limonite, within which may occasionally be seen particles of native gold. The calcite is partly dissolved and partly changed to fragile cellular pseudomorphs of quartz. The development of earthy hydrous oxide of manganese is very characteristic of the oxidation of the calcitic veins of the district, and large portions of the lodes are made up of soft, dark, manganiferous earth, associated with residual masses of the original quartz and calcite and containing vugs and druses of secondary deposits of these two minerals.

All the ore thus far mined or opened is more or less oxidized and, as a rule, contains no sulphides. In the Original Bullfrog mine there is a little chalcocite, or copper glance, and in some undeveloped veins in the schists south of Beatty there are specks of galena, but the only sulphide thus far found in the other deposits is pyrite. Native gold, alloyed with various proportions of silver, is the only valuable constituent of most of the ores, although cerargyrite, or horn silver, is fairly abundant in the rich ore of the Montgomery-Shoshone mine. The gold is finely divided and is almost invariably found in the quartz, not in the calcite. Its characteristic association with little limonitic specks, representing oxidized pyrite, has already been referred to.

The ores, as sacked and shipped in the first year or two of activity, ranged from $100 to $700 a ton, but the deposits on the whole are very much lower in grade than those at Goldfield and the future of the district depends on the milling of material that will not average over $15 a ton.

The proportion of silver varies greatly in different mines, even when these are close together.

PART I.—GENERAL GEOLOGY.

By W. H. Emmons and G. H. Garrey.

PRE-TERTIARY ROCKS.

CRYSTALLINE METAMORPHIC FORMATIONS.

GENERAL DISTRIBUTION.

Bare Mountain, which lies to the southeast of the Bullfrog Hills, is composed largely of crystalline rocks, consisting in the main of quartzite, marble, and mica schists. In the Bullfrog Hills exposures of these rocks are restricted to the southern margin and in the area shown on the map (Pl. I) they occur at only two places, one about a mile south of Beatty and another south of the Original Bullfrog mine, these areas together covering only about 1 square mile. South of Beatty, in the southeast corner of the district, the structure of the schists is relatively simple, but in the area south of the Original Bullfrog mine pegmatite injections are so closely spaced that, in mapping on the usual scale, it is impossible to separate the pegmatite from the schists. To facilitate description the two areas will be discussed separately.

SCHISTS SOUTH OF BEATTY.

General character.—The crystalline rocks south of Beatty are in the main quartz-biotite schists, containing relatively thin bands of marble, and calcite-muscovite schists with subordinate bands of quartz-muscovite schists. The schists rest upon a quartzite equally metamorphosed and apparently belonging to the same series. The marble members of the series are much lighter in color than the quartz-biotite schists, are easily recognized, and may be followed along the strike for considerable distances. They furnish datum planes from which the structure of the rocks may in most cases be worked out and have been shown separately on the geologic map. The rocks are closely folded and as a rule dip northeastward.

Quartzite.—Quartzite is the oldest member of the series exposed in this locality, though it is quite possible that mica schists of greater age occur at horizons below the quartzite. The largest area of the quartzite forms the summit (elevation 3,640 feet) of the ridge 6,700

feet S. 40° E. of Blackcap Mountain, where it is brought into contact with the mica schist and limestone by a fault trending about northwest. The quartzite strikes nearly northwest and dips northeastward about 35°. East of this point, about 700 feet, it is again brought into contact with the mica schist by a fault trending northeast. To the west of this quartzite block are two smaller areas of quartzite overlain by mica schists in apparent conformity.

The quartzite is a grayish-brown rock with vitreous luster and is composed of small quartz grains of nearly uniform size, between which are a few flakes of biotite. The microscope shows that the quartz grains have been recrystallized and that their sawtooth boundaries are closely interlocking. A little muscovite has in places been developed between the grains. The rounded borders of the quartz grains remain only where they were partly protected by plates of mica. The undulatory extinction of all the quartz grains shows that they have been subjected to great strain. A little chlorite, rutile, and zircon are present. The quartzite is the metamorphosed product of a comparatively clean quartz sand too poor in alumina to form sufficient mica to give it a schistose structure. The muscovite, biotite, rutile, and zircon are of later age than the quartz and were formed during the process of metamorphism.

Quartz-biotite schist.—The quartz-biotite schist is the predominating crystalline rock and its thickness probably exceeds all other members of the series combined. The rock is dark gray, of satin-like luster in hand specimens, and appears to be composed almost entirely of flakes of black and white mica, whose parallel arrangement gives the rock a perfect schistosity. The microscope shows a great deal of quartz as small grains of nearly uniform size. In some varieties rounded grains of orthoclase, microcline, and sodic plagioclase are mingled with the quartz and in a few specimens calcite fills the interstices between the quartz grains. A considerable quantity of magnetite occurs in irregular patches, the longer axes of which lie parallel to the schistosity. A little rutile and zircon are present. Chlorite occurs as an alteration product of biotite. Certain layers of the biotite schist contain a few small garnets, which on microscopical examination prove to be greatly crushed and cemented together by biotite and muscovite. In the deformation of this rock the quartz grains, which are original, were rotated and oriented with the schistosity. The mica flakes, though occasionally bent, show much less deformation than the quartz, which proves that the quartz grains were rotated before the mica now surrounding them was formed and probably while they were embedded in clay.

Interbedded with the quartz-biotite schist are layers of quartz schist in which there is present a little muscovite but practically no biotite. In this rock the schistose structure is less developed than

in the quartz-biotite schist. It is intermediate in composition between the latter and the quartzite, and in mapping has been included with the quartz-mica schist.

Marble and calcite schist.—The quartz-biotite schist grades also through calcite schist into nearly pure marble. On the south slope of the hill (elevation 3,520 feet) 6,200 feet S. 52° E. of Blackcap Mountain, three of these calcareous bands are present, one separated from the other by about 40 feet of quartz-biotite schist. The calcareous bands are long, thin lenses, usually from 5 to 40 feet thick, but at some places for a short distance along their strike thickening to nearly 100 feet. The schistosity is as a rule approximately parallel to the contacts of the quartz-biotite schist, though locally it makes considerable angles with them.

As a rule the rock which forms the calcareous bands is a gray or brown marble, nearly pure, in which the calcite grains are of nearly uniform size, a little less than 1 millimeter in diameter. There are a few flakes of white mica in this rock, but biotite is rare or absent. In places the marble grades into calcite schist by the addition of muscovite flakes, which are about 1 millimeter in diameter and have a parallel orientation, thus giving schistosity to the rock. Thin layers of calcite schist rich in quartz and biotite are locally present in the marble. The same minerals occur in the calcite schist as in the quartz-biotite schist, though there is much less biotite and considerably more calcite in the latter.

Pegmatite and quartz veins.—A few pegmatite veins and a larger number of quartz veins cut the schists. Such veins are most abundant in the more siliceous rocks and were not noted at all in the limestones. Most of these veins occur as rudely tabular bodies less than 2 inches wide, but a few of them have a width of several feet. These veins are represented both by quartz-filled fissures which run in various directions across the beds and by bunchy lenticular quartz veins parallel to the schistosity. They do not as a rule appear to be persistent in length and some of the outcrops are not much longer than they are wide. The pegmatite veins are composed of crystals of feldspar, quartz, and muscovite. Most of these crystals are less than an inch in diameter and many of them are shattered and crushed. Under the microscope orthoclase, microcline, and albite are seen to be present. The feldspars are closely interlocking with quartz and are for the most part of the same age, though small quartz veinlets, almost paper thin, cut the pegmatite. The pegmatite does not occur in rocks younger than the schists and is presumably pre-Silurian. The larger quartz veins, which are as abundant and more widely distributed than the pegmatite veins in the crystalline schist area south of Beatty, are composed almost entirely of quartz, but some of them contain a few paper-thin veinlets of white mica. These

white quartz veins also carry a little galena in places. At one locality bunchy lenticular quartz veins in schist are distinctly cut by the pegmatite dikes. Quartz veins of the character of these in the crystalline schist area do not occur in the Tertiary lavas and accordingly, while there may be veins of different ages, all of them are probably pre-Tertiary.

Origin, stratigraphy, and age.—The schists south of Beatty are very clearly metamorphosed sandstones, shales, and limestones. When these sedimentary rocks were formed the conditions changed rapidly, so that thin beds of quartz sand containing a few rounded feldspar grains and some clayey material alternated with shales and limestone. The beds were metamorphosed under considerable pressure. The original quartz grains lost their rounded character and were cemented into a dense vitreous quartzite, in places squeezed to quartz schist. The shales, composed of clay containing numerous very small quartz grains and some iron oxide, were changed to mica schists, the character of the resulting schists depending on the proportion of quartz, clay, and iron compounds originally present. The pure limestones were recrystallized to marbles and those which contained more or less clay became calcite schists.

There was, so far as can be judged, very little addition of material to the sedimentary rocks in their metamorphism, but merely a partial chemical rearrangement of their elements to produce new minerals and a physical rearrangement of sand grains in the shales by which their longer axes were oriented in a nearly parallel direction and with the schistosity. In the more quartzose members, where there was only a little clay present, there was no such rearrangement of the quartz grains, since there was much less freedom of movement, a condition supplied by the softer clay.

The attitude of the metamorphosed series is defined at most places by the thin beds of included limestone and quartzite. (See Pls. IV, *A*, and V, *A*.) The usual dip is northeastward, but varies considerably, owing to the close folding to which the beds have been subjected. This is best shown on the summit of the ridge (elevation 3,640 feet) 6,700 feet S. 40° E. of Blackcap Mountain, just south of the border of the map, where a sigmoidal outcrop of one of the limestone layers indicates a narrow syncline pitching to the north. The predominant strike of the schistosity is to the northwest, approximately parallel to that of the bedding, and it dips at most places from 15° to 35° NE. In some places, however, the schistosity crosses the bedding, as is shown in Plate IV, *B*.

Overlying the schists there is a blue or buff limestone, not so much metamorphosed and less coarsely crystalline than the marbles of the schists. It has not been subjected to the close folding which has involved them, and is therefore younger, presumably Silurian,

A. METAMORPHOSED LIMESTONE IN SCHISTS 2 MILES SOUTH OF BEATTY.

B. INTERBEDDED QUARTZITE AND MICA SCHIST SOUTH OF BEATTY SHOWING DIVERGENCE OF SCHISTOSITY AND BEDDING.

though no fossils were found at this place. The crystalline schists and the overlying limestone are faulted against the Tertiary rhyolites by the Amargosa fault, which is described on pages 74–75.

COMPLEX SOUTH OF THE ORIGINAL BULLFROG MINE.

General character.—The crystalline rocks south of the Original Bullfrog mine in the southwestern corner of the area of the special map are much more varied than those south of Beatty and record a more eventful geologic history. They include quartz-biotite schist, quartzite, and marble, which inclose small masses of sheared diorite or kindred igneous rocks. This complex is cut by pegmatite, which varies from bodies perhaps 100 feet across to paper-thin sheets that follow the cleavage planes of the schist. The pegmatite is also sheared and crushed, though not nearly so much as the rocks it cuts. Sheared rocks composed of quartz-biotite schist and pegmatite, in which the larger feldspars are drawn out into eyelike bodies, form augen gneiss. The pegmatite is in turn cut by veins of pure-white quartz, carrying a little pyrite. A quartz diorite dike cuts the crystalline rocks, and this in turn is cut by a diorite dike rich in hornblende. The schists are also cut by a branching dike of quartz porphyry which closely resembles the Tertiary lavas in general appearance and is probably of the same age.

Quartz-biotite injection schist, pegmatite, and augen gneiss.—Quartz-biotite injection schist, pegmatite, and augen gneiss form the larger part of this crystalline complex. The quartz-biotite schist is very much like that which occurs in the areas south of Beatty and like it is presumably metamorphosed shale. It is dark gray, with biotite as the most conspicuous mineral. The dip of the schistosity is from 40° to 60° E. At almost every outcrop there are light-colored layers of pegmatite composed of feldspar, quartz, and muscovite, paralleling the schistosity of the rock or in a few places crossing it. These vary from layers not much thicker than paper to those many feet across. Commonly a single sheet swells and narrows so as to appear in cross section as a number of lenses, joined end to end. Some adjacent pegmatite layers join, inclosing small, elongated masses of schist. Certain areas, some of them more than 100 feet across, are entirely pegmatite and in these the individual feldspars and quartz crystals are large, many of them several inches in dimension. The injections of pegmatite between the leaves are often closely spaced in the biotite schist and the resulting rock is finely streaked with thin alternating white and black layers of almost equal thickness. Where these layers are less closely spaced the rock becomes an injection gneiss. Figure 2 is a sketch of quartz-biotite schist which has been injected by pegmatite. In this sketch the very thin pegmatite bodies are not shown.

The schist, as seen under the microscope, is composed of quartz grains of nearly uniform size, rotated so as to lie nearly parallel with the cleavage and forming thin layers in places only one crystal thick. A little mica is associated with the quartz. Biotite is the more abundant mica and with muscovite occurs as overlapping scales, which together make almost continuous sheets alternating with quartz. Very subordinate amounts of magnetite, colorless garnet, rutile, and zircon are present. The pegmatite layers are a little thicker than the biotite or quartz layers and some of them are bounded on both sides by continuous layers of mica flakes, showing that the injection took advantage of the perfect cleavage of mica to enter the schists. Here and there rounded grains of orthoclase and sodic plagioclase occur among the quartz grains of the schist, but most of the feldspar is restricted to the pegmatite bands. The pegmatite consists of quartz, orthoclase, microcline, albite, oligoclase, and muscovite, with

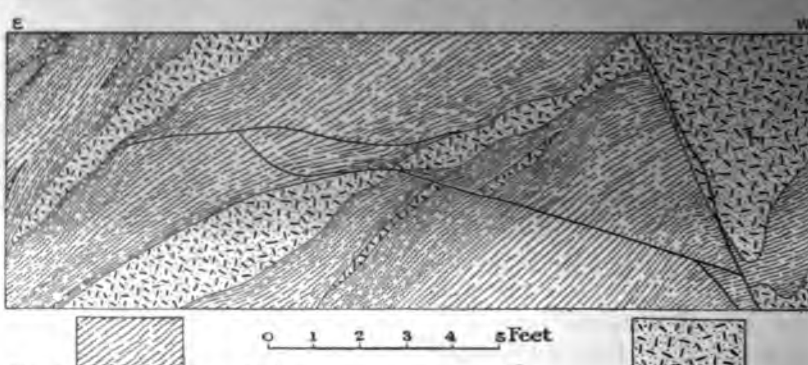


FIGURE 2.—Quartz-biotite schist cut by pegmatite. Many thin injections along the lamination of the schist are not shown. Sketch of the south side of a prospect pit south of the Original Bullfrog mine.

a little biotite, magnetite, and pyrite. The proportion of these minerals varies considerably in different places. The quartz and the feldspar crystals are much larger than those of the original schist and are more varied in size. They are closely interlocking and developed contemporaneously. At many places large crystals of feldspar up to one-half inch in diameter cause an appreciable swelling in the injection, especially where the pegmatite veins are narrow.

Quartz schist and quartzite.—Included within the quartz-biotite schist are layers or lenses of quartz schists and quartzite of about the same composition as those south of Beatty (see p. 20); but the quartz schist south of the Original Bullfrog mine has undergone greater metamorphism. In some of it the quartz grains have been mashed so that they are two or three times as long as they are thick, the longer axes lying in the direction of the schistosity. The quartzite and quartz schist grade into the quartz-biotite schist and are not con-

A. INTERBEDDED SCHIST AND QUARTZITE SOUTH OF BEATTY, SHOWING PARALLELISM OF SCHISTOSITY AND BEDDING.

B. SHALY VARIETY OF RHYOLITE NO. 1, WEST SLOPE OF SUTHERLAND MOUNTAIN.

tinuously exposed. They are not distinguished from the biotite schist on the map and the field evidence is insufficient for correlating them with the quartzite south of Beatty.

Marble.—About 200 feet S. 14° W. from the Big Bullfrog hoist there is a small outcrop of marble surrounded by quartz-biotite schist and by surface débris. The contact of the two rocks is not exposed, but the general appearance of the marble is much like that associated with the schist south of Beatty. It is much more coarsely crystalline than the overlying Silurian limestone presently to be described and it contains a little tremolite. It is presumably older than Silurian and probably belongs to the crystalline series.

Sheared diorite.—Just east of the Big Bullfrog shaft and trending N. 46° E. is an elongated area of a very dark schist which appears to be surrounded by quartz-biotite injection schist. A dike of the same material is shown in a prospect pit 250 feet S. 15° E. of the Big Bullfrog shaft. This dike has a trend of N. 5° E. and a dip of 35° E. Similar rocks occur at two or three other places lying loose upon the surface in the area of the crystalline schists, and it is probable that their distribution is more general than is indicated on the map. Under the microscope the rock is seen to be composed of hornblende, andesine, pale garnet, titanite, biotite, and zircon. Considerable quartz is present, but it is probably not original. The igneous rock has been subjected to the same kind of metamorphism that affected the sedimentary rocks, and has a well-developed schistosity. At no place was the sheared diorite observed in contact with the other schists, but it is presumably later than them and probably represents dikelike bodies that cut the sedimentary rocks from which the schists were formed.

Quartz veins.—Quartz veins are very numerous in the area of the crystalline schists. These vary in size from mere films to bodies several feet across. At most places they are pure, milky-white quartz, much like the quartz associated with feldspar and mica in the pegmatite. Veins of gray quartz and some of opalescent quartz are also present. They contain little or no calcite or other carbonates, such as are present in nearly all of the veins which cut the Tertiary lavas. The quartz veins in the crystalline area carry a little muscovite and magnetite and some of them inclose small masses of pyrite, which on the surface are in part oxidized. Some of these veins are said to contain a little gold, but none has been found rich enough to mine. These veins are not clearly separable from the pegmatites, as in one or two places pegmatite veins, 1½ feet or more wide, were seen to grade into massive pyrite, bearing white quartz with only an occasional small bundle of muscovite plates. The normal pegmatite, near where it grades into quartz, also shows the pyrite with oxidized borders, and this pyrite is in some places crystallized partly in the quartz and

partly in the orthoclase feldspar. Possibly some of these veins are contemporaneous with the galena-bearing veins in the crystalline-schist area south of Beatty. The veins are undoubtedly not all of the same age, but some of them are younger than the pegmatite, since they cut both the pegmatite and the diorite dikes which intersect both the pegmatite and schist. The quartz in many of the most recent veins in the crystalline-schist area in the southwest corner of the district is of a grayish color. Under the microscope very minute quartz veinlets are seen to lie in the cleavage of crushed plagioclase of the pegmatite, showing that they were formed subsequently to the crushing movements.

Quartz diorite dike.—On the west slope of the low hill (elevation 4,020+ feet) in the southwest corner of the area studied a quartz diorite dike, trending a little east of north, cuts the schists and pegmatite. It is from 10 to 30 feet wide and is exposed almost continuously for about 1,800 feet. It is in turn cut by a more basic diorite dike and at the intersection its north end is offset toward the west. It is a light-colored, greenish-gray, fine-grained rock, containing a few small phenocrysts of hornblende. Under the microscope the texture is seen to be porphyritic. The rock is greatly decomposed and consists essentially of sericitized feldspar, in the main acidic plagioclase, intergrown with quartz, hornblende, and pyroxene. Much chlorite is present as a decomposition product of hornblende. Since this rock has no well-developed schistosity, it was presumably intruded into the schists after they were metamorphosed and it may be of Tertiary age.

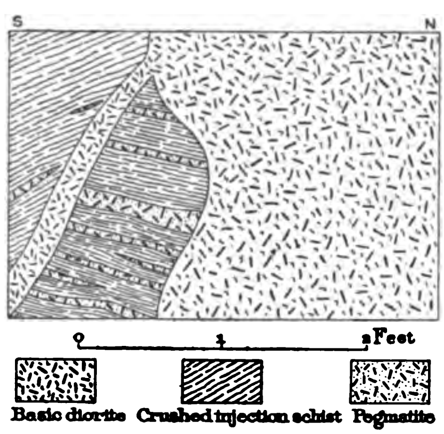


FIGURE 3.—Diorite intruding quartz-biotite injection schist and pegmatite; exposed in a prospect pit south of the Original Bullfrog mine.

Diorite dike.—A few feet south of the summit of the low hill (elevation 4,020+ feet) in the southwest corner of the area the schists, pegmatite, and quartz diorite dike are cut by a diorite dike, striking nearly due east and dipping about 50° N. Owing to the relation of its dip to the topography the outcrop curves northward at both ends, making a nearly semicircular band. The basic diorite is a dark-gray rock, relatively fresh, and contains many small crystals of hornblende and feldspar. Under the microscope it is seen to have a granular structure, and is composed of greenish-brown

hornblende, oligoclase, orthoclase, quartz, apatite, titanite, magnetite, and zircon, with chlorite and calcite as alteration products. Hornblende constitutes about half the rock. The relation of the diorite to the schists and pegmatite is shown in figure 3. As shown by the map (Pl. I), the quartz diorite dike is offset or faulted by the basic diorite dike and is therefore the older of the two. Small quartz veinlets cut the diorite dike at several places.

SUMMARY.

The two areas of crystalline schists, one shown in the southeast corner and the other in the southwest corner of the special map, probably belong to the same general series of metamorphosed sedimentary rocks, but owing to the great metamorphism which they have undergone it is impossible to correlate them with certainty. Aside from the degree of pegmatization, the two series closely resemble each other lithologically. About a mile west of the northwest corner of the area shown on the Bullfrog map Silurian fossils were found in an unmetamorphosed limestone near and presumably overlying the crystalline series, showing that the folding and other processes of metamorphism took place in pre-Silurian time. The crystalline rocks must therefore be Ordovician or older. Briefly stated, their geologic history is as follows: A pre-Silurian series of shales and sandstones containing layers of limestone and intruded by basic igneous rocks was folded under such conditions as to develop very few fractures in the shales and limestones. At this time a well-defined schistosity was developed, at many places highly inclined to the original bedding planes. In both areas, but especially in the southwestern one, pegmatite was subsequently injected into the planes of schistosity and locally across them. Associated with this pegmatite, and probably of the same or slightly later age, are white quartz veins, probably of pegmatitic or igneous origin. After pegmatization the rocks were crushed and sheared again, but not so much as before, and quartz cemented the crushed minerals. Subsequently this complex was cut by a quartz diorite dike and later by a diorite dike rich in hornblende. Still later quartz veins cut the schists and diorites. The complex was also cut by a dike of quartz porphyry, probably in Tertiary time.

SILURIAN (?) LIMESTONE.

At two places in the area shown on the special map limestone overlies the crystalline schists. One of these is south of Beatty, where a long, narrow strip of limestone trending a little east of north is bounded on the west by the Amargosa fault. Another is just south of the Original Bullfrog mine and extends for about one-fourth mile northeast and southwest of it. A third area, 1 mile S. 83° E. of this mine,

has a similar lithologic character and is probably of the same age; while a fourth outcrop is 2,500 feet S. 52° E. of Velvet Peak. Nearly everywhere this limestone is blue or buff and it is marbleized only where it is brecciated. The dense appearance distinguishes it from the more calcareous members of the crystalline rocks, which are everywhere crystallized to marble; muscovite, which is everywhere present in the latter, has not been noted in the younger limestones. On the south slope of the hill on which the Original Bullfrog mine is located several feet of soft red shaly material overlies the limestone and separates it from the Original Bullfrog vein quartz. To the east, near the Bullfrog Extension mine, this soft material is lacking but is probably equivalent in age to a much harder rock layer which resembles a silicified shale or a very fine grained dark-gray quartzite. The Bullfrog Extension shaft, which is inclined about 18° N., is driven practically on the dip of this dark-gray shalelike rock, which at this point appears to have a thickness of about 25 to 35 feet, as shown by its outcrops and by the cross section afforded by a shaft sunk through the shale about 200 feet northwest of the Bullfrog Extension mine.

Some 300 to 400 feet south and southeast of the Bullfrog Extension mine remnants of what appear to have been a quartzite layer are found between the shales and the bluish-gray, supposedly Silurian limestone. This quartzitic rock grades into the limestone below. Quartzite also overlies the limestone a mile S. 83° E. of the Original Bullfrog mine and has at its base gritty or conglomeratic beds. The exposed beds of limestone, quartzite, and gray shale are altogether probably less than 150 feet thick and on the map are all shown by the same pattern. The limestones are massive and the shales disturbed, but the strike of the contact as determined from exposures near the Original Bullfrog mine is N. 70° E. and the dip about 15° to 20° N. The sedimentary rocks strike more nearly east and dip at lower angles than the rhyolites lying to the north.

The limestone formation near the Original Bullfrog lithologically resembles one containing Silurian fossils, which outcrops about a mile west of the northwest corner of the area shown on the special map. These fossils were submitted to Mr. E. O. Ulrich, and his report on them is given below:

The lot of imperfect fossils collected near Bullfrog, Nev., submitted for determination, proved of unusual interest and importance. The fauna is unquestionably Silurian in age and the collection, though manifestly incomplete, is to be counted among the few far-western collections referred to this age that are sufficiently complete to make their age determination quite satisfactory. As a rule throughout the West the Silurian is underlain by much thicker deposits of Ordovician limestone, and the Silurian element of a section does not comprise more than from 50 to 100 feet at the top. If a quartzite—perhaps followed by a dark shale—overlies the limestone, both the quartzite and shale are likely to be of Devonian age.

Provisionally determined, the following genera and species are represented in the collection:

- Cyathophyllum sp. near radiculum.
- Streptelasma cf. spongaxis.
- Streptelasma cf. conulus.
- Omphyma cf. verrucosum.
- Cystiphyllum sp. undet.
- Stromatoporella sp. undet.
- Heliolites interstinctus.
- Calopœcia? sp. undet.
- Cœnites sp. undet.
- Cœnites sp. undet. (2).
- Conchidium knighti?

The country is much faulted and the two outcrops of limestone could not be connected, but from general relations and similar lithologic character it is highly probable that the limestone overlying the schists is Silurian and that the quartzite and shale may be Devonian, but it is unsafe to make the correlation on lithologic grounds alone in this area, where faults of great throw are numerous.

TERTIARY VOLCANIC ROCKS.

LAVA FLOWS AND TUFFS.

INTRODUCTORY STATEMENT.

The stratiform Tertiary volcanic rocks include a great variety of eruptives, some of which are repeated many times in the series. There are sixteen rhyolite flows, five basalt flows, one flow of quartz latite, and one of quartz basalt. Sedimentary tuffs occur at two horizons between the flows. The general sequence is shown in the columnar section of figure 4. In the field the contrast between the different types is very sharp and in most instances the contacts between different formations of the same type are well marked. By the method of treatment followed here the earliest flow is described first and the succeeding flows are taken up in order of their age. Thus the descriptions of the five basalt flows are interspersed between the descriptions of rhyolites each at its appropriate place, as determined by its age relations—after the formation upon which it rests and before the formation which overlies it. Flows of the most basic type are shown to follow the flows of the most acidic type, and this sequence has taken place five times near the close of the period of the Tertiary eruptives; quartz latite and subsequently quartz basalt followed the fifth eruption of basalt.

GENERAL CHARACTER OF THE RHYOLITES.

The rhyolites of the Bullfrog district are in the main flows and flow breccias. They are nearly related mineralogically and chem-

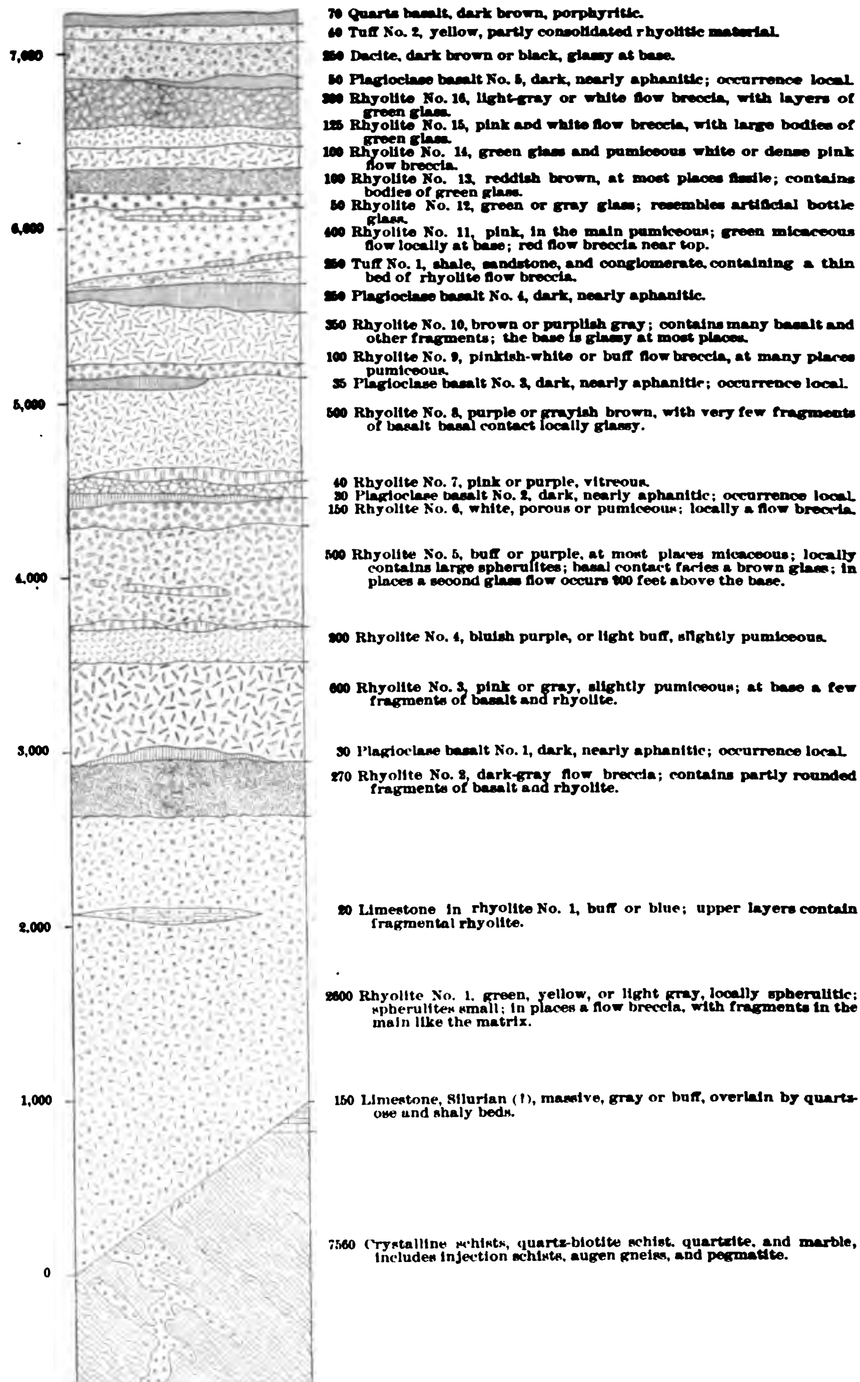


FIGURE 4.—Generalized columnar section of the Bullfrog district. Figures at left of section indicate scale in feet. Figures at right indicate thickness in feet.

ically, as is shown by petrographic examination and by the following partial analyses of material taken from widely separated horizons:

Partial analyses of rhyolite flows of the Bullfrog district.

[G. Steiger, analyst.]

Locality.	No. of rhyolite flow from base.	Reference in this paper.	SiO_2.	CaO.	Na_2O.	K_2O.
		Page.				
North slope Bullfrog Mountain	5	39	75.35	0.65	3.52	5.26
West slope Velvet Peak	(a)	44	73.71	1.20	3.35	3.01
Southeast slope Busch Peak	8	43	77.26	.58	2.96	4.65
West slope Burton Mountain	12	51	71.60	1.90	3.30	4.22

a Glass at base of 8.

The flows may be readily distinguished one from the other by differences in color and structure, or by the character of fragments contained, and less readily by slight mineralogical differences. The sixteen rhyolite formations shown on the map do not all represent individual flows, nor does the interpretation of the geologic history of the region necessitate as many divisions as have been made. The units mapped, however, are those which may with practice be recognized in the field and which therefore are most useful in working out the geologic structure. The individual flows range in thickness from 20 feet or less to about 2,600 feet. Some of them wedge out or become thin, but most of them are persistent throughout the area. The combined thickness of the sixteen formations is more than 6,000 feet. S. H. Ball[a] regards the rhyolites as early Miocene, but the evidence for this conclusion is not so complete as is desirable.

GENERAL CHARACTER OF THE BASALTS.

Six flows of basalt are interbedded with the rhyolites and tuffs. The first five are ordinary plagioclase basalts so nearly alike, both in appearance and in mode of occurrence, that it is impossible to distinguish them one from the other, except on stratigraphic evidence gained by the association of recognized rhyolite flows. These basalt flows are hardly so persistent in occurrence as the rhyolite flows, nor do they attain such great thicknesses. The plagioclase basalt flows are interbedded with the rhyolite flows and are therefore of contemporaneous age. Basalt No. 6 is a quartz-bearing plagioclase basalt and is the youngest lava flow of the series.

a Ball, S. H., Bull. U. S. Geol. Survey No. 308, 1907, Pl. I.

DETAILED DESCRIPTIONS.

RHYOLITE No. 1.

Occurrence and distribution.—Rhyolite No. 1 is the lowest member of the series of Tertiary volcanic flows exposed within the Bullfrog area. All its visible contacts with the Paleozoic limestone and with the crystalline schists are due to faulting, and search outside of this area has failed to reveal the original base of the volcanic series. So far as known, there is no other flow below rhyolite No. 1, and it may rest directly upon the limestone or in part upon the crystalline schists. In the southeast corner of the area mapped a small block of Paleozoic limestone is faulted up into this rhyolite in such a manner as to suggest that the two formations occur close together in the geologic section there and that probably no great thickness of Tertiary rocks ever intervened between them. Rhyolite No. 1 is well exposed in Box Canyon, where it covers an area of more than 1 square mile. It forms the hills just west of the mouth of the canyon and probably underlies the flat to the north. It is also the rock of the low hills west of Sawtooth Mountain and occurs a few rods northwest of the Original Bullfrog mine. In the southeast corner of the area mapped there are several blocks of rhyolite No. 1 that are entirely surrounded by fault contacts with other rocks. A similar fault block occurs northeast of Beatty, just outside of the area mapped. The maximum thickness of the formation is probably not much greater than 2,600 feet. This, however, is only an estimate, since the base of the formation is not exposed.

General character.—Rhyolite No. 1 is a series of flows which includes a thin bed of limestone. The flows, though all of about the same chemical composition, vary considerably in texture and appearance. In color they are green, yellow, and light gray. The groundmass is fine grained or glassy and at most places contains phenocrysts of dull or glassy feldspar, quartz, and mica and rarely a crystal of hornblende. Feldspar is by far the most abundant and in certain facies quartz phenocrysts are entirely wanting. Where there are few quartz phenocrysts the groundmass is, as a rule, spherulitic and in places the rock is made up almost entirely of spherulites. These are uniform in size and appearance and where the material between them has weathered out they resemble small peas. None of the spherulites are more than one-fourth inch in diameter.

In some places the rhyolite is a flow breccia, the fragments being for the most part of the same material as the matrix. Fragments of basalt, which are abundant in the overlying flow breccia, are here very rare. The inclosed rhyolite fragments are, as a rule, small, but are never rounded. At many places these fragments are bright green and contrast strikingly with the dull, greenish-gray matrix.

A. APPARENT BEDDING IN RHYOLITE NO. 1, NORTHWEST OF BUCK SPRING.

B. NEARER VIEW OF PART OF PLATE VI, *A*, SHOWING ARKOSE-LIKE TEXTURE, DUE TO CLOSE CROWDING OF FELDSPARS.

The commonest variety is massive, slightly porphyritic rhyolite, but locally the rock is so finely banded and of such fine grain that it may be readily mistaken for shale. This resemblance is increased by a perfect parting between the bands on weathering, as is shown in Plate V, *B*. More massive layers of rhyolite are associated with the fissile variety, grading into them and dipping in the same direction. These layers are composed of a dense groundmass containing phenocrysts of feldspar, which are concentrated along parallel planes in such a manner as to give the appearance of an arkose sandstone (see Pl. VI, *B*)—a texture which is most typically developed in the gulch west of Sawtooth Mountain. The apparently shaly or sandy rhyolites, as a rule, dip eastward with other rhyolite flows. In Box Canyon there are several irregular bodies of the fissile rhyolite up to 20 feet in diameter, inclosed by the usual porphyritic variety of rhyolite No. 1. These appear to be blocks broken off by movement in the lava before it solidified.

Microscopical character.—In the normal facies of rhyolite No. 1 the texture is porphyritic and the groundmass exceeds the phenocrysts in volume. The larger phenocrysts are orthoclase, plagioclase, embayed quartz, and biotite, with very rarely a crystal of hornblende. All of these, except quartz, show crystal outlines. Smaller grains or crystals of magnetite, microcline, and apatite are present. The phenocrysts of orthoclase, which are most abundant, are partly altered to kaolin. The plagioclase is albite or oligoclase. Chlorite, serpentine, limonite, and sericite occur as aggregates, resulting from decomposition; calcite is very abundant as a secondary mineral, formed presumably in the process of weathering.

The groundmass is glassy or microcrystalline and the glassy varieties are in most cases devitrified. At many places the groundmass is made up almost entirely of spherulites. These are small spherical bodies, from 1 to 4 millimeters in diameter, composed largely of glass that contains a great number of minute rods of quartz and feldspar radiating from the center of the sphere. In some there is a shell of chloritic material near the surface of the spherulite, through which the radial rods pass. The spherulites completely or partly inclose phenocrysts of feldspar and biotite, but the large embayed quartz phenocrysts present at many places in this flow are not found in the most spherulitic varieties.

The banded fissile shaly rhyolites have a groundmass of brown glass inclosing microscopic phenocrysts of quartz and feldspar; the arkose-like beds have a glassy or indistinctly spherulitic groundmass, containing phenocrysts of the same minerals that are visible to the naked eye. The phenocrysts in this facies are concentrated in thin sheets parallel to the apparent bedding, giving the rock the banded appearance which is its most striking characteristic in the

field. The bright-green color of the fragments in the brecciated varieties is due to a more nearly complete chloritization of their ferromagnesian constituents.

Limestone in rhyolite No. 1.—A thin layer or member of blue or buff limestone occurs at a few places in rhyolite No. 1. One exposure is about one-half mile north-northwest of Bullfrog Mountain, and another is on the east slope of the hill one-third mile northwest of Buck Spring. The layer is from 10 to 30 feet thick and dips eastward with the rhyolite. The upper part is thin bedded and contains fragmental rhyolite material, so that in a few localities these beds are almost indistinguishable from the arkose-like rhyolite which lies above them. The limestone is about 500 feet below the top of rhyolite No. 1.

Under the microscope the limestone appears finely crystalline, and it contains, besides calcite, minute dark opaque bodies, which may be organic material. Chalcedonic silica is segregated in small bodies throughout the rock.

The limestone was probably laid down in a shallow basin during a period of relative quiescence between the time of the outpouring of the rhyolite flows which occur below and above. The three outcrops mentioned are probably portions of the same bed.

Age and origin.—The first rhyolite is the earliest Tertiary formation exposed in the area mapped. It records at least two outpourings of lava, separated by a period of time long enough for the formation of 30 feet of limestone; this period was not necessarily great, for limestone may be formed in shallow basins at a relatively rapid rate. The rhyolites below and above the limestone are indistinguishable in the field and in the laboratory, and it is probable that similar conditions of eruption and cooling prevailed during the formation of the flows. The broken rhyolite fragments in the flow-breccia facies are of the same material as the matrix and show that movement of the lava continued after solidification had begun. The planes of fissility which separate the shaly or sandy layers are not to be regarded as the limits of separate flows. The banding was probably caused by a spreading out of local concentrations of phenocrysts of quartz and feldspar by the motion of the cooling and still liquid or viscous lava before complete solidification took place. Since the eruption of rhyolite No. 1 it has been tilted so that it now dips eastward at angles up to 40°.

RHYOLITE No. 2.

Occurrence and distribution.—Rhyolite No. 2 lies above rhyolite No. 1 and is conformable with it in dip. It is generally overlain by rhyolite No. 3, though there is in some places a flow of basalt between. Rhyolite No. 2 outcrops on the southwest slope of Bullfrog Mountain,

just north of the Original Bullfrog mine (see Pl. I), where it is in contact, by faulting, with Silurian (?) limestone. It occurs also on the lower parts of the slopes of Sawtooth Mountain and on the peak just south of it, and thence extends eastward for a few rods beyond the bottom of Box Canyon. There are no other outcrops of this rhyolite in the Bullfrog area. In the mountains to the east of Box Canyon it is either wanting or is covered by more recent flows. The thickness of this formation west of Bullfrog Mountain is about 400 feet.

General character.—Rhyolite No. 2 is a flow breccia—that is, a lava which in flowing has gathered up fragments of its own congealed and broken crust or fragments of other rocks. The rock is dull purplish gray, grayish white, or dull pink and contains many fragments of various kinds. The matrix has an aphanitic groundmass, which does not appear glassy in hand specimens. It contains inconspicuous phenocrysts of dull white feldspar, quartz, and mica. Most of the fragments, some of which are partly rounded, are less than 2 inches in diameter and consist of basalt, rhyolite, and dark glass. Most of them are distinctly darker than the matrix. Though they occur persistently throughout the formation, they are most abundant near its base. The character and quantity of fragments distinguish this flow from those below and above it.

Microscopical character.—The texture of the matrix is porphyritic, the phenocrysts being orthoclase, quartz, oligoclase, biotite, and apatite. These are embedded in a glassy or partly devitrified groundmass which exhibits lines of flow suggesting an eutaxitic texture. Calcite is abundant in some thin sections. The matrix contains fragments of spherulitic rhyolite, brown glass, devitrified porphyritic rhyolite, and basalt. The rhyolite fragments are very similar to and were probably derived from rhyolite No. 1, which lies below this flow. The basalt fragments have a groundmass in which the parallel arrangement of the small feldspars shows flowage. The phenocrysts are plagioclase, altered olivine, magnetite, and biotite. The embedded fragments are generally more decomposed than the matrix.

Age and origin.—This rhyolite flow breccia was erupted after rhyolite No. 1. The fragments are very largely pebbles or detrital material which it picked up as it flowed along the surface. Much of this material came from the earlier rhyolite (No. 1) over which it flowed. The basalt fragments are not unlike the plagioclase basalt flows of the Bullfrog area (Nos. 1 to 5), but since the earliest basalt flow known in this district lies above rhyolite No. 2, the basalt pebbles must be from a still earlier though similar basalt flow, which has been eroded or is now covered up by later formations. The abundant foreign material in this flow breccia shows that there was a period of erosion between the extrusion of the first and second rhyolites.

Apparently rhyolite No. 2 was spread upon a nearly level surface, but it has since been tilted so that it now dips steeply toward the east.

PLAGIOCLASE BASALT No. 1.

Occurrence and distribution.—The earliest basalt flow exposed in the Bullfrog area occurs above rhyolite No. 2 and below rhyolite No. 3. It outcrops on the slopes of the peak south of Sawtooth Mountain, where it forms the conspicuous dark faulted band visible from the flat northeast of the Original Bullfrog mine. West of the summit of this mountain this flow is about 40 feet thick, but it thins rapidly toward the north and there is only a small isolated remnant on the west slope of Sawtooth Mountain. Plagioclase basalt No. 1 dips eastward with the associated rhyolites.

Petrography.—Basalt No. 1 is a very dark, rather weathered rock, which is almost aphanitic but contains a few red or green specks of altered olivine. In places it is vesicular, especially near the base, and the vesicles as a rule are filled with light-colored secondary minerals. Basalt No. 1 closely resembles later plagioclase basalts and can not be distinguished from them lithologically. Its identification depends, therefore, on its association with certain rhyolite flows. Microscopical study shows no essential differences between the plagioclase basalts. A description of basalt No. 3, based on the examination of fresher and more abundant material than was available for the study of basalt No. 1, is given on page 44.

Age and origin.—Basalt No. 1 probably represents a single flow that followed closely the intrusion of the flow breccia, rhyolite No. 2, which lies below it. The flow breccia has a nearly uniform thickness below every exposure of the basalt and apparently no erosion occurred between the two eruptions. There was, however, some erosion after the basaltic eruption, for the isolated remnants of basalt above the flow breccia indicate that it was once more extensive and was removed in part before the outpouring of the third rhyolite.

RHYOLITE No. 3.

Occurrence and distribution.—Rhyolite No. 3 lies conformably above the first basalt. On the south slope of Bullfrog Mountain and on the west slope of Sawtooth Mountain basalt No. 1 is wanting, and rhyolite No. 3 rests upon rhyolite No. 2. Rhyolite No. 3 forms the summit and most of the south spur of Sawtooth Mountain and covers a large area to the northeast of this peak, but does not extend eastward far beyond the bottom of Box Canyon. On the west slope of Sawtooth Mountain rhyolite No. 3 is broken by northeast-southwest faults into several blocks, which are successively depressed to the northwest. On the west slope of Sawtooth Mountain its thickness is about 750 feet, but it thins to the west and on Bullfrog Mountain is

probably not more than 500 feet thick. It dips east with the other lavas.

General character.—Rhyolite No. 3 is a slightly pumiceous or vesicular pink, light-brown, or light-gray rock, which contains phenocrysts of feldspar, quartz, and black mica. The basal part of the sheet contains a few small dark fragments of rhyolite and basalt and by reason of this resembles rhyolite No. 2 in color and texture, but the inclosed fragments are smaller and less abundant. The two rhyolites, if they were not separated by the basalt flow on the peak south of Sawtooth Mountain, might be considered a unit. The upper part of the sheet is, as a rule, a darker pink or brown than the basal part and shows flow lines. Narrow lenticular cavities from 1 inch to 2 inches long and one-eighth inch thick occur throughout the upper half of the formation. These are bubbles or vesicles drawn out by movement during the cooling of the lava. Many of them are filled with chalcedonic quartz.

Microscopical character.—In this rock, which is porphyritic, the groundmass greatly exceeds in volume both phenocrysts and fragments. It is glassy, in places pumiceous, but nowhere spherulitic, and is only slightly devitrified. The phenocrysts are quartz, orthoclase, plagioclase, magnetite, biotite, and apatite. Plagioclase, though less abundant than orthoclase, occurs in larger phenocrysts, some of them with a length of 3 millimeters. They range in composition from albite to sodic andesine. Biotite is fresher than in the rhyolite previously described, and quartz is not so much resorbed.

Age and origin.—Rhyolite No. 3 represents one or more lava flows that followed the extrusion of basalt No. 1. The time intervening between the two eruptions was probably short, but was long enough for the partial erosion of basalt No. 1.

RHYOLITE No. 4.

Occurrence and distribution.—Rhyolite No. 4 lies conformably above rhyolite No. 3 and under the basal glass of rhyolite No. 5. It occurs just west of the summit of Bullfrog Mountain, which its rudely semicircular outcrop partly incloses. It is also exposed on the west slope of Sawtooth Mountain, where it is faulted into several short overlapping blocks. Its exposures are confined to these localities. It is approximately 200 feet thick on Bullfrog Mountain and somewhat less than that on Sawtooth Mountain.

General character.—This rhyolite is in most places bluish purple or light buff, but locally may be almost white. It is slightly pumiceous and consequently its surface is dull and spongy. It is as a rule nearly aphanitic, but a relatively rare facies shows a considerable number of phenocrysts. Of these, quartz and glassy feldspar are the most abundant; black mica and magnetite occur sparingly.

Included fragments are rare and those present appear to be of the same composition as the matrix. The most pumiceous portions appear as blotches, surrounded by denser or lithoidal rhyolite. The blotches appear to be mainly due to the development of a vesicular texture in place, but some of them may be included fragments of a more pumiceous rhyolite.

Microscopical character.—The groundmass, which exceeds the phenocrysts in volume, is usually devitrified and contains minute particles of quartz, feldspar, magnetite, and biotite. The biotite, however, is not conspicuous in hand specimens. Some of the microphenocrysts may be due to incipient devitrification, but most of them are probably original. The groundmass also incloses larger phenocrysts of the same minerals. Of these, quartz is more abundant than orthoclase and plagioclase is less abundant than either. Rhyolite No. 4 is more porous than the upper portion of rhyolite No. 3 and is consequently more decomposed. Biotite is magmatically altered and is replaced by minute crystals of magnetite. Small fragments of the same composition as the matrix are present in some parts of the flow.

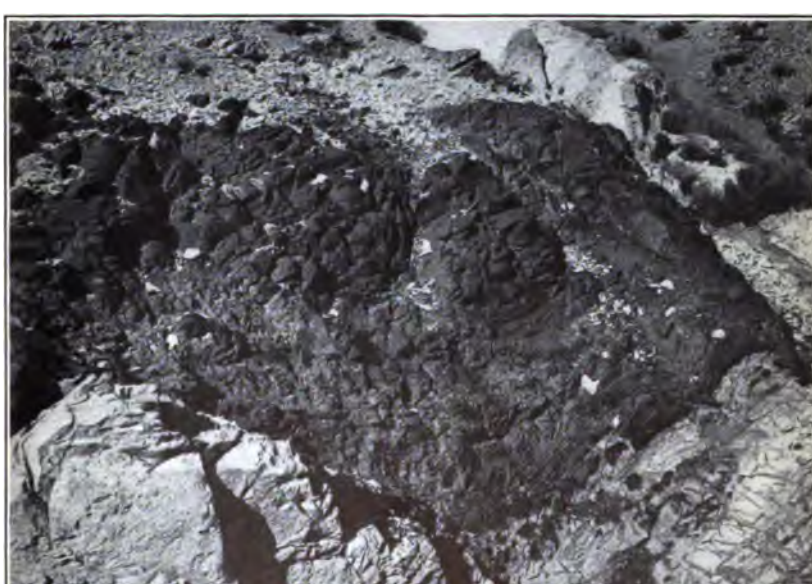
RHYOLITE No. 5.

Occurrence and distribution.—Rhyolite No. 5 forms the summit of Bullfrog Mountain (see Pl. I) and, dipping east nearly with the surface, covers a large part of the north and south slopes. It also forms the summit and most of the east slope of Sawtooth Mountain. It becomes thicker to the east and is exposed over almost the entire southeast slope of Sutherland Mountain for a vertical distance of 800 feet. On Ladd Mountain it is the buff to pale purplish-gray rock that lies below the conspicuous white layer on the west slope. (See Pl. XI, *A*.)

General character.—Rhyolite No. 5, though presenting several facies, usually has characteristics that distinguish it from the other rhyolites. At Bullfrog Mountain it is a compact purple rock, at many places containing rhyolite fragments which are slightly pumiceous and of lighter color than the matrix. Quartz, glassy feldspar, and black or bronze mica phenocrysts are present. In some varieties mica phenocrysts are very abundant and serve to distinguish this rock from all other rhyolites in the district.

The lower part of the formation is exposed only on Bullfrog Mountain and on the south slope of Sawtooth Mountain. At both localities a band of brown glass, with a maximum thickness of about 20 feet, forms the base of the flow. Near the summit of Sawtooth Mountain a similar glass occurs about 200 feet above the base. These glass bands are at most places distinct and easily recognized and are convenient horizons for tracing boundaries and faults. The glass is of approximately the same chemical composition as the more

A. SPHERULITES IN RHYOLITE NO. 5, ON SAWTOOTH MOUNTAIN.



B. AN INCLUSION OF BASALT IN RHYOLITE NO. 6, IN THE SADDLE BETWEEN SUTHERLAND MOUNTAIN AND BUSCH PEAK.

crystalline rhyolite, but contains fewer phenocrysts. In some varieties the groundmass constitutes as much as 90 per cent of the rock.

Spherulites are common in rhyolite No. 5. They are numerous at the base of the west slope of Ladd Mountain and on the summit of Sawtooth Mountain (Pl. VII, *A*), but are most strikingly developed east of Beatty, about one-half mile beyond the eastern border of the area mapped. A few occur on Bullfrog Mountain, but they are rare on the slopes of Sutherland Mountain. The spherulites are globular rhyolitic bodies, commonly from 2 to 12 inches in diameter, but some of them are much larger; for example, some of those east of Beatty are 3 or 4 feet in diameter. They are, as a rule, purplish gray, though brown when in the basal glass, and do not differ markedly from the lithoidal facies in color and texture. Only when the rock is slightly weathered is the bounding surface of the sphere conspicuous. Southeast of Sutherland Mountain rhyolite No. 5 is nearly aphanitic, dense, and of a light-buff tint. Toward the west and south this facies grades into the purple micaceous facies.

Distinguishing features.—The formation is so variable in appearance that it is likely to be confused with other rhyolites. It is distinguished from rhyolite No. 1 by its fresher aspect, by the greater size of its spherulites, and at some places by the presence of many large, dark mica phenocrysts, which are never abundant in the older rhyolite. It differs from rhyolite No. 3 in having locally a spherulitic crystallization and more and larger crystals of biotite. Small fragments of basalt, such as occur at places in rhyolite No. 3, are rare or wanting in rhyolite No. 5.

Microscopical character.—The rock is porphyritic; the groundmass is glassy, in some places microspherulitic, in many macrospherulitic. The spherulites contain macrophenocrysts, though hardly as many as the lithoidal portions of the rock. Where not spherulitic, the groundmass is, as a rule, composed of minute alternating light-brown and colorless bands of glass, which curve around the phenocrysts and around the few angular rhyolite fragments that are present, suggesting an eutaxitic texture. The phenocrysts are orthoclase, biotite, quartz, albite, oligoclase, and magnetite. They are similar in size and character to the phenocrysts of the other rhyolites, with the exception of the biotite crystals, which are, as a rule, much larger and more numerous. Orthoclase is commonly more abundant than all other phenocrysts. Magnetite is relatively rare. The phenocrysts are comparatively fresh; orthoclase is slightly kaolinized; mica is in some places altered; chlorite and calcite are present in a few sections. A partial analysis of a specimen from the lithoidal portion of this flow is the first one given in the table on page 31.

The basal glassy contact facies under the microscope shows a groundmass similar to that of other facies, but is more largely glass, is of a darker color, and contains fewer phenocrysts.

Age and origin.—Rhyolite No. 5 consists of two or more lava flows, which followed closely the eruption of rhyolite No. 4. The glassy layers are not distinct eruptions, but are the rapidly cooled basal parts of successive flows.

RHYOLITE No. 6.

Occurrence and distribution.—Rhyolite No. 6 lies conformably above rhyolite No. 5 and is covered by basalt No. 2, or, where that is wanting, by rhyolite No. 7. It is the conspicuous white layer which from the town of Rhyolite is plainly visible on Busch Peak and on Sutherland and Ladd mountains. Its distribution is wider than that of any of the earlier rhyolites, since it occurs near both the eastern and western borders of the area mapped and is repeatedly exposed in many of the intervening fault blocks. The thickness of the formation varies from a few feet on the east slope of Bullfrog Mountain and near the head of Box Canyon to about 300 feet on the south slope of Montgomery Mountain.

General character.—Rhyolite No. 6 is at most places a porous or pumiceous flow breccia containing basalt and other fragments, some of which are of considerable size. Light-colored rhyolite fragments are more abundant but less conspicuous than those of basalt. In the most common or pumiceous facies the matrix is, as a rule, pure white, a characteristic which distinguishes this flow from all other rhyolites of the series. Locally, the denser varieties have a pale-pink color. Only a few phenocrysts are present, namely, quartz, clear feldspar, and black mica. In places there are dendritic figures in the fracture planes, due to the infiltration of manganese compounds, possibly derived from the overlying basalt. Fragments of other rhyolite, of basalt, and fragments like the matrix are included, and some of them are slightly rounded.

Microscopical character.—The texture is porphyritic. The groundmass, which constitutes more than 80 per cent of the rock, is composed almost entirely of cellular or pumiceous glass. The cavities are lined or filled with secondary quartz. Phenocrysts of quartz, orthoclase, plagioclase, and mica are small and nowhere abundant. All except orthoclase are unaltered, and as a rule it also is fresh. The plagioclase ranges from albite to calcic oligoclase. Calcite is present as a secondary mineral. A dark, opaque mineral in minute particles, probably manganese dioxide, forms mosslike aggregates.

Basalt bodies in rhyolite No. 6.—On the saddle between Sutherland Mountain and Busch Peak and on the slopes below it, both east and west, there are several long, narrow bodies of basalt, some of which are vertical or nearly so. Viewed from a short distance away, these

have every appearance of basalt dikes. Some of them are only 6 to 12 inches wide, of nearly uniform width, and from 30 to 40 feet long, while others are several feet in width and up to a hundred feet in length. One of these masses is shown in Plate VII, *B*. Close inspection shows that the rhyolite is the younger rock, for its flow lines are clearly influenced by its contact with the basalt, as is shown in figure 5, which is a sketch of the contact of the two rocks. Rhyolite apophyses fill indentations in the basalt, and angular fragments of basalt are considerably more numerous in the rhyolite immediately in contact with the basalt than they are a short distance away. This latter feature suggests that the larger basalt bodies are probably blocks caught up in the flow rather than that they are dikes intruded into a still viscous rhyolite. Such contacts were not noted anywhere else in the area. The blocks are of such local distribution that they are not distinguished on the map (Pl. I), but are colored like the intrusive basalt.

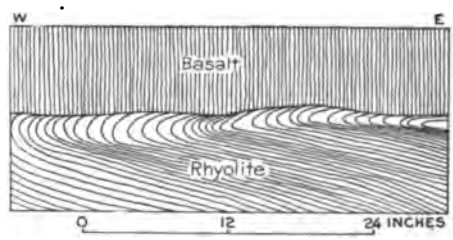


FIGURE 5.—Section of the contact between rhyolite No. 6 and an included mass of basalt.

PLAGIOCLASE BASALT No. 2.

Occurrence and distribution.—Plagioclase basalt No. 2 is a flow that lies conformably above rhyolite No. 6 and below rhyolite No. 7. With the exception of a small patch in the saddle east of Bullfrog Mountain this basalt is exposed only in the mountains between Box Canyon and the town of Rhyolite. To the east of Rhyolite it is wanting, as is shown by the many exposures of the section at the horizon where it should appear. Its maximum thickness is about 60 feet. The dip of basalt No. 2 is very gentle on the slopes of Busch Peak, but is much steeper on the east slope of Bonanza Mountain.

Microscopical character.—Basalt No. 2 is a dark, dense, nearly aphanitic though usually vesicular rock resembling basalt No. 1. Under the microscope it exhibits a groundmass composed of roughly parallel lath-shaped plagioclase crystals with a smaller amount of glass, magnetite, and microcrystalline white silicates in the interstices between the laths. The groundmass incloses large phenocrysts of olivine. The plagioclase is altered and is largely replaced by minute shreds of calcite or sericite. Much of the olivine has been replaced by silica which is as a rule stained by limonite. The groundmass contains chlorite and serpentine. Most of the vesicles are filled with secondary minerals, which commonly are thin films of calcite surrounding spheres of chalcedony.

Age and origin.—There was no considerable erosion between the eruption of rhyolites No. 6 and No. 7, for the latter always rests upon rhyolite No. 6 where basalt No. 2 is absent. The basalt, then, was never an extensive flow and its original limits were probably but little greater than those indicated by its present exposures.

RHYOLITE No. 7.

Occurrence and distribution.—Rhyolite No. 7 rests conformably either upon basalt No. 2 or, where that is eroded or not present, upon rhyolite No. 6. Rhyolite No. 7 is one of the most constant in color, distribution, thickness, and general appearance, and for that reason is of especial value as an aid to the interpretation of structure. It is exposed on Bullfrog Mountain, Sawtooth Mountain, Bonanza Mountain, Sutherland Peak, Busch Peak, Ladd Mountain, Montgomery Mountain, and on each of the ridges to the southeast of Montgomery Mountain. Its maximum thickness is about 50 feet.

Microscopical character.—This rhyolite varies in color from pale to deep pink or pinkish purple. As a rule it is vitreous and it is everywhere slightly porphyritic. The phenocrysts are quartz, clear feldspar, and subordinately biotite. At some places the rock is rather porous, owing to the presence of minute lenticular masses of spongy or pumiceous rhyolite. Small fragments of other rocks occur at places in this rhyolite, and basalt fragments are in some places numerous. These were apparently picked up by the rhyolite as it flowed over basalt No. 2.

Under the microscope the groundmass is seen to be glassy and fresh and to have nearly everywhere an eutaxitic texture. The phenocrysts are orthoclase, quartz, albite, biotite, magnetite, and apatite, the last two being very small.

RHYOLITE No. 8.

Occurrence and distribution.—Rhyolite No. 8 lies upon rhyolite No. 7 except on the north slope of the peak east of Bullfrog Mountain, where for a short distance rhyolite No. 7 is wanting. It is as widely distributed as rhyolite No. 7 and since it is much thicker it covers a larger area. It forms most of Bullfrog, Bonanza, Ladd, Montgomery, and Paradise mountains and of the ridges southeast of the last named, but its greatest development is on Busch Peak and in the low hills to the east. Most of its exposures form dip slopes on the east sides of the mountains and ridges. Its thickness varies from 400 to 800 feet.

Microscopical character.—Aside from its brown and dark-gray glassy basal facies, rhyolite No. 8 is clear purple at most places, but locally, especially where weathered, it is purplish gray, dark grayish brown, or nearly white. The groundmass is close and even and at

many places vitreous. Here and there it contains a great many white blotches less than an inch in diameter, which are in the main included fragments of spongy rhyolite, but some appear to have been pumiceous or frothy spots drawn out by movement in the cooling lava. There are invariably phenocrysts of clear feldspar and quartz. Biotite flakes, though present at places in considerable quantity, are smaller and not as conspicuous as those in rhyolite No. 5. Fragments of other rocks are nowhere abundant and those which do occur in this flow are rhyolites of various darker shades than the matrix. The brown basalt fragments, which are very numerous in rhyolites No. 9 and No. 10, are rare indeed in rhyolite No. 8. This difference is important, since in many cases it is the only characteristic which distinguishes rhyolite No. 8 from rhyolite No. 10. Under the microscope the texture is seen to be porphyritic; the groundmass, which in volume exceeds the phenocrysts, is glassy and the more vesicular portions are devitrified. Commonly flow lines encircle the phenocrysts, which are quartz, orthoclase, albite, oligoclase, and biotite. Small grains of magnetite and crystals of rutile are present in some specimens.

A chemical analysis of a specimen from this flow, made by Mr. George Steiger in the Survey laboratory, is given below. According to the quantitative system of classification the rock is an alaskose, a very siliceous subrang to which many rhyolites belong.

Analysis of rhyolite No. 8 from the southeast slope of Busch Peak (B. 374).

[George Steiger, analyst.]

SiO_2	77.26	H_2O+	.96
Al_2O_3	11.54	TiO_2	.18
Fe_2O_3	.85	CO_2	None.
FeO	.13	P_2O_5	Trace.
MgO	.20	MnO	.03
CaO	.58	BaO	None.
Na_2O	2.96	SrO	None.
K_2O	4.65		
H_2O-	1.03		100.37

Basal facies.—At many places where the base of rhyolite No. 8 is exposed the basal facies is a brown or dark-gray glass about 50 feet in maximum thickness. At some places, as on Sutherland Mountain, Ladd Mountain, and Busch Peak, it is either entirely lacking or is represented only by a semivitreous facies. The glassy layer is also lacking for short distances at a few points along the base of rhyolite No. 8 in the numerous outcrops southeast of Montgomery Mountain. This glass grades into the purple rhyolite and is therefore the contact facies of the flow. The phenocrysts in the glass are the same as those in the overlying purple rhyolite; the matrix,

though distinctly glassy and showing perlitic cracks, has about the same composition as the matrix of the rest of the flow. A partial chemical analysis of this glass is the second one given in the table on page 31. The analysis shows that the glass contains a slightly higher percentage of lime and soda than the lithoidal facies, but this may not be true for large masses, since the minerals of the phenocrysts in the two facies are in about the same proportion in each.

PLAGIOCLASE BASALT No. 3.

Occurrence and distribution.—Plagioclase basalt No. 3, where present, overlies rhyolite No. 8 and underlies rhyolite No. 9. It is not a persistent flow, but it is present at several places on the low hills southeast of Busch Peak, on the west slopes of Montgomery Mountain, and in the ravine northeast of Ladd Mountain. At many places on the low hills and ridges southeast of Montgomery Mountain the basalt is wanting and rhyolite No. 9 rests directly on ryholite No. 8. Its maximum thickness is 50 feet, but at most places it is much thinner. The number and widespread distribution of basalt fragments in overlying rhyolites Nos. 9 and 10 suggest that basalt No. 3 once covered a large area and was eroded before the extrusion of rhyolite No. 9.

Microscopical character.—Basalt No. 3 is, as a rule, less weathered than basalts Nos. 1 and 2, and phenocrysts of olivine are visible at many places on fresh surfaces, but it does not differ otherwise in general appearance from the earlier basaltic flows. The microscope shows that the denser facies from the middle of the flow are holocrystalline, but vesicular contact facies contain a variable proportion of glass. In the more crystalline varieties the groundmass is made up of labradorite laths of various sizes, between which are smaller crystals or grains of augite, magnetite, apatite, titanite, biotite, hematite, chlorite, and serpentine. Phenocrysts of olivine, distinctly larger than the plagioclase laths, show characteristic alterations to serpentine and iron oxides.

RHYOLITE No. 9.

Occurrence and distribution.—Rhyolite No. 9 overlies plagioclase basalt No. 3 or, where that is absent, rests directly upon rhyolite No. 8. Its maximum thickness is about 250 feet, but in most places it is less than 60 feet thick. Half a mile north of Busch Peak rhyolite No. 9 is wanting and the glassy basal portion of rhyolite No. 10 rests directly upon rhyolite No. 8. Rhyolite No. 9 is more easily eroded than rhyolites Nos. 8 and 10 and consequently is not a conspicuous member of the series. It never caps hills, but is exposed in saddles or on slopes. It dips east with the associated lava beds.

Microscopical character.—Rhyolite No. 9 is at most places a pinkish-white or buff, more or less pumiceous flow breccia; but on the low hills east of Busch Peak it is purple or purplish pink and rather compact. As a rule it contains many small fragments of dense gray rhyolite, gray pumiceous rhyolite, and basalt. The phenocrysts are quartz, clear feldspar, and biotite.

Where pumiceous this formation is easily recognized, but the denser facies is likely to be mistaken for rhyolite No. 10 where the basal glass of the latter is not present. Where only a few basalt fragments occur in rhyolite No. 9 the dense purplish variety is likely to be confused with rhyolite No. 8, unless basalt No. 3 intervenes.

Under the microscope the texture is seen to be porphyritic; the groundmass, which exceeds the phenocrysts in volume, is glassy and in the more pumiceous varieties devitrified. The phenocrysts are quartz, orthoclase, albite, and oligoclase. A little biotite is present, and altered varieties contain limonite.

RHYOLITE No. 10.

Occurrence and distribution.—Wherever its base is exposed rhyolite No. 10 rests upon rhyolite No. 9, except at a point 2,500 feet north of Busch Peak, where it rests upon rhyolite No. 8. It is overlain conformably by basalt No. 4. Rhyolite No. 10 is exposed at many places in the central and eastern portions of the Bullfrog area, where, like rhyolite No. 8, it forms the eastern dip slopes of many of the hills. The summits of most of the smaller hills northeast, east, and southeast of Busch Peak, of Montgomery and Paradise mountains, and of Velvet Peak are composed of this rock. The thickness of the flow is fairly uniform and attains a maximum of about 400 feet.

General character.—The base of rhyolite No. 10 is nearly everywhere a grayish-brown to brownish-black glass, with a maximum thickness of 20 feet. This grades upward into the less glassy facies, which constitute the greater part of the formation. Except the basal glass, rhyolite No. 10 is brownish gray or purplish gray and contains fragments of rhyolite, basalt, and, rarely, schist. The matrix has many phenocrysts of quartz and feldspar and a few biotite flakes. The lower part of the formation, including the glass, is a flow breccia containing at most places many fragments of basalt and dark rhyolite, which are less numerous in the upper part. The purple varieties are not so bright and clear in tint as those of rhyolite No. 8, and where the rock is slightly weathered it is rusty and is generally a little lighter in color than rhyolite No. 8.

Rhyolite No. 10 may be easily confused with the least pumiceous varieties of rhyolite No. 9, but the upper surface of the latter flow is almost everywhere clearly defined by the glassy base of rhyolite No. 10. Rhyolite No. 10 is at most places easily distinguished from

hyolite No. 8 by the greater number of dark fragments which it contains and especially by the presence of basalt fragments, but on the slopes of the hills just west of the Indian Springs road, which skirts the west base of Rainbow Mountain, foreign fragments are very rare in the upper part of rhyolite No. 10, and the two formations may therefore be confused where the lower part of rhyolite No. 10 is faulted out of sight.

Microscopical character.—The texture of all varieties is porphyritic. The basal facies is composed of fresh brown or nearly colorless glass, in most sections eutaxitic and containing phenocrysts of quartz, orthoclase, albite, oligoclase, magnetite, and biotite, with fragments of basalt and devitrified rhyolite. The minute bands of the groundmass curve around both phenocrysts and fragments. The middle and upper parts of the formation have a glassy groundmass, in places devitrified and locally spherulitic, which contains phenocrysts and fragments similar to those of the basal facies and a large number of minute grains of quartz and feldspar without crystal outlines (anhedrons), which are not present in such quantity in the basal glass. The less vitreous appearance of the upper part of the formation is probably due largely to its more numerous phenocrysts.

PLAGIOCLASE BASALT No. 4.

Occurrence and distribution.—Plagioclase basalt No. 4 lies above rhyolite No. 10 and below either rhyolite No. 11 or tuff No. 1 where the latter two are present. The basalt is conformable with the associated beds and dips toward the east at high angles. It is exposed on the west slope of Rainbow Mountain, on both sides of the Indian Springs road, near the border of the area mapped, and also in the flat three-fifths of a mile S. 40° W. of Black Peak. It also occurs as a long, narrow strip about 1,600 feet east of the Montgomery-Shoshone mine and covers a large area along the road between the Montgomery-Shoshone mine and Beatty. It also forms a large part of the lower northeast slope of Velvet Peak and of the ridge which extends northwest from this peak. Dipping with the slope of this mountain it descends to the flat and disappears below tuff No. 1. There is no cliff exposure where its thickness can be measured, but the width of its outcrop and the steep inclination of associated beds indicate that it is much thicker than any preceding basalt flow. The width of outcrop of the flow to the southeast of Paradise Mountain is explained in part by a strike fault. But even with such a fault the maximum thickness of this flow is about 500 feet. This thickness, however, may be local, for it appears less at the exposure of this flow on the west slope of Rainbow Mountain.

A narrow block of this basalt occupies a part of the Montgomery-Shoshone fault zone, as described on pages 106–108.

Microscopical character.—In the field and under the microscope basalt No. 4 closely resembles basalt No. 3, which is described on page 44. Both are vesicular at many places. At two localities in the Bullfrog district outcrops of leucite basanite at the horizon of basalt No. 4 are partly or entirely surrounded by the basalt. In the preliminary account[a] of this district basalt No. 4 was described as leucite basalt. The study of additional material shows that the flow as a whole is a plagioclase basalt, but contains relatively small masses of leucitic rocks, of which the more crystalline are leucite basanite rather than leucite basalt. The leucite basanite is further described on page 58.

TUFF No. 1.

Occurrence and distribution.—Volcanic tuffs, including some shale, sandstone, and conglomerate, are exposed at several places along the road between Beatty and the Montgomery-Shoshone mine. The sedimentary rocks rest upon plagioclase basalt No. 4 and underlie a green micaceous rhyolite flow breccia—the base of rhyolite No. 11. At no place is a complete section of these rocks exposed, and on account of their narrow distribution and intergradations the several members have been mapped together.

At a point 3,000 feet N. 81° E. of the Montgomery-Shoshone mine shale is exposed in a prospect on the west slope of the low hill north of the forks of the road, where it is faulted against rhyolite No. 10 to the east and is apparently shattered by the movement. The shale also occurs north and east of this hill in a flat, where its presence is shown only by débris on the surface; it is also exposed east of the road and about 400 yards southeast of the summit of this hill in a prospect where it is much disturbed and dips 55° E. This dip is apparently local, for it is steeper than that of associated beds. Southeast of this point the shale, here containing calcareous concretions and septaria, lies directly upon basalt that dips about 20° E. Shale is exposed also on the northern end of the ridge that extends northwest from Velvet Peak; it dips approximately with the slope of the hills. Toward the southeast the shale becomes very thin or disappears, for conglomerate beds occur within a few feet of the top of the basalt with approximately the same dip. The conglomerate is very coarse, bowlders of rhyolite and basalt more than 1 foot in diameter being very common. The material of many of these can be identified with that of earlier lava flows. Above the conglomerate are a few feet of fissile calcareous sandstone which, on the parting planes, show cylindrical worm impressions. These beds are not persistent, as they were not found to the north of this outcrop.

About 3,000 feet S. 3° E. of Burton Peak a fine-grained unconsolidated sandstone containing many small pebbles, mainly basalt, out-

[a] Op. cit., p. 49.

crops just below the base of rhyolite No. 11. Though the base of this member of the tuff is not exposed, it apparently lies above the calcareous sandstone and probably grades laterally into the green shale that, farther north, lies immediately below the base of rhyolite No. 11. It thus appears that the green shale that outcrops at the northwest end of this group of discontinuous exposures of sedimentary rocks is probably contemporaneous with and equivalent in age to the conglomerates, sandstone, and shale at the southeast end. About 900 feet northwest of the bench mark (3,547 feet) on the Beatty road south of Burton Peak a small, low knob, defined by the 3,560-foot contour on the topographic map, rises above the flat. This knob, entirely surrounded by wash, is composed of rhyolite flow breccia. The matrix is a light porous gray rhyolite and contains fragments of basalt and rhyolite, many of which are more than 2 feet in diameter. It does not resemble any of the principal rhyolite formations and is assumed to be a flow which occurred during the formation of the tuff. On account of its very small area it is not separated from the tuffs in mapping. The average thickness of this entire group of sedimentary rocks is estimated at 250 feet.

Microscopical character.—The green shale, which at the northwestern end of the area covered by the tuff makes up the entire thickness of the sedimentary beds, is seen under the microscope to be composed mainly of small particles of glass, sometimes arranged with their longer axes approximately parallel. Very minute crystals of calcite and a little mica and magnetite are also present. Chlorite is abundant and gives the rock its green color.

The fissile calcareous sandstone with worm impressions is made up largely of very small angular quartz fragments and smaller calcite aggregates, with a few angular fragments of feldspar, mica, and magnetite and some secondary chlorite.

The conglomerate beds contain many bowlders that have the same microscopical character as rhyolite No. 10. The basalt fragments are in the main decomposed, are very vesicular, and have their vesicles filled with calcite; they are similar to the basalt of the first, second, and third flows, but no leucite basanite was noted.

Age and origin.—The sedimentary rocks, which collectively constitute tuff No. 1, were deposited in water after the eruption of basalt No. 4. The fresh condition and angular outlines of many of the fragments show that they were not subjected to great weathering or to long transport by running water, and much of the material may have fallen as volcanic débris directly in water, where it mingled with water-borne débris. The rhyolite flow breccia contained in the formation represents a lava flow of small extent which was extravasated while the tuffs were being formed.

RHYOLITE No. 11.

Occurrence and distribution.—Rhyolite No. 11 outcrops on the west slope of Rainbow Mountain, where it lies above basalt No. 4 and, like it, dips east. It also forms most of the lower slopes of Burton Peak and extends east as far as Beatty. A broad area of this rhyolite is exposed because strike faults which have vertical displacement less than the thickness of the rhyolite repeat its outcrops. South of Burton Peak this formation rests on tuff No. 1. Where it is not a capping formation it is overlain by rhyolite No. 12. Its thickness is about 700 feet.

General character.—Rhyolite No. 11 is made up of a number of thin flows and flow breccias, the lowest of which is a pale-green micaceous flow breccia, at most places about 5 feet thick. About a mile east of the Montgomery-Shoshone mine, on the Beatty wagon road, this green flow lies directly on the shaly green tuff. It is easily distinguished from other formations which overlie it and is the base of every exposure of the formation between the Montgomery-Shoshone mine and Beatty. Its frequently faulted outcrop approximately parallels the road and may be traced almost continuously for more than a mile. It has not been recognized on the west slope of Rainbow Mountain. Here the basal members of rhyolite No. 11 are less consolidated than the upper ones and may represent a mud flow which covered this area before the eruption of the upper members.

Pink flows of varying thickness lie above the green micaceous flow, giving a total thickness of 600 to 750 feet. The larger portion of the formation is pumiceous and spongy, though at several localities it is very dense, the two facies grading laterally one into the other. The groundmass is dull or vitreous, according to the density of the rock, and contains phenocrysts of feldspar, partly resorbed quartz, and black mica. There is a considerable range in the relative abundance of the phenocrysts, black mica being very abundant in the basal flow and comparatively rare in the upper ones. Small fragments of rhyolite, basalt, and crystalline schists are at most places present, though as a rule they are not abundant. Near the top of the division there is a prominent red flow breccia, composed chiefly of rhyolite fragments, some of which are a foot or more in diameter. This flow, though not separately mapped, is persistent and has proved a useful structural datum plane.

Microscopical character.—The texture of rhyolite No. 11 is porphyritic; the groundmass is a devitrified glass, here and there spherulitic, and as a rule it exceeds in volume the phenocrysts of orthoclase, quartz, albite, oligoclase, biotite, magnetite, and apatite. Of the minute included fragments rhyolite is most abundant, basalt is common, and schist is rare. No leucite basanite could be identified among the fragments examined. The color of the basal green mica-

ceous flow is due to chlorite, probably an alteration product of biotite. The red flow breccia near the top of the formation owes its color to a staining of the groundmass by iron oxide.

RHYOLITE No. 12.

Occurrence and distribution.—Rhyolite No. 12 lies conformably above rhyolite No. 11 and is exposed as a narrow band about 40 feet wide on the west slope of Rainbow Mountain. This band is faulted to the east, just north of the Steinway mine, and forms a narrow strip trending west of north on the west side of the ridge upon which is the Steinway shaft. The same flow outcrops around the summit of Burton Mountain and forms the conspicuous green band on the west slope. Here its thickness is about 70 feet.

General character.—This flow is a green or gray glass, streaked at some places with pinkish bands, and contains a few small phenocrysts of feldspar and quartz. It is invariably fresh, of vitreous luster, and both in appearance and mode of fracture it closely resembles green bottle glass. Flow lamination is developed at many places and the alternating green, gray, or pink bands, less than 1 inch thick, are a striking feature of the formation.

Microscopical character.—A glassy, perlitic groundmass constitutes 95 per cent of the rock. It is generally brown in thin section, is not devitrified, and contains small phenocrysts of quartz, orthoclase, oligoclase, biotite, magnetite, hornblende, and hypersthene, and minute prisms of augite. The groundmass immediately surrounding the femic (ferromagnesian) crystals is bleached and the resulting halos contrast strikingly with the brown groundmass. They are very slightly birefringent and vary in width with the size of the minerals which they surround. The biotite scales, for example, are from 1 to 2 millimeters in diameter and have halos from 0.2 to 0.4 millimeter wide, and prisms of hypersthene about 0.3 millimeter thick and twice as long are surrounded by halos 0.15 millimeter wide. The halos are of equal width on ends and sides of crystals and are not present around quartz or feldspar. The crystallites are concentrated in bands, most of them less than 1 inch thick, and in the bands there is a partial linear orientation of the longer axis of the crystallites. Their discoloring effect upon the groundmass, when they are closely spaced, produces the pink bands noticeable in hand specimens. It is perfectly clear that the ferromagnesian minerals continued to grow after the lava came to rest and that in the process of growth they absorbed from the still liquid magma those constituents that give it color. In the part of the magma from which this subtraction took place incipient crystallization began and proceeded far enough to give a slight birefringence to the glass of the halos. The effects of absorption extend farther into the groundmass around the larger

crystals, but when volumes are considered the crystallites or small crystals have been increased proportionately more than the larger ones.

A chemical analysis of rhyolite No. 12, made in the Survey laboratory, is given below. According to the quantitative system of classification the rock is tehamose, a type reported from California, Montana, and elsewhere:

Analysis of rhyolitic glass (B. 164) from the west slope of Burton Peak, 50 feet below the summit.

[George Steiger, analyst.]

SiO_2	71.60	TiO_2	0.25
Al_2O_3	12.44	ZrO_2	.01
Fe_2O_3	1.00	P_2O_5	.08
FeO	.65	MnO_2	.06
MgO	.06	BaO	.03
CaO	1.90	SrO	.03
Na_2O	3.30		
K_2O	4.22		100.22
H_2O	4.59		

Age and origin.—Rhyolite No. 12 is probably a single flow whose eruption closely followed rhyolite No. 11. It was formerly more widely distributed than it is at present and, together with rhyolite No. 11 and later formations, it has probably been eroded from the hills south of the Montgomery-Shoshone mine and perhaps from the mountains west of Rainbow Mountain.

RHYOLITE No. 13.

Occurrence and distribution.—Rhyolite No. 13 followed closely the extrusion of rhyolite No. 12 and outcrops as a narrow band paralleling this rock on the west slope of Rainbow Mountain. It also forms the summit, the knoll on the western spur, and most of the eastern slope of Burton Mountain. Its maximum thickness is about 200 feet.

General character.—Rhyolite No. 13 is in the main reddish brown or grayish brown, but in places contains layers of green glass that resemble rhyolite No. 12. Rhyolite No. 13 has a dense, glassy groundmass and contains a few phenocrysts of feldspar, quartz, hornblende, and mica. Intricately curving flow lines are strikingly developed at every outcrop and at most places weathering has produced a parting between them which distinguishes this flow from the other rhyolites.

Microscopical character.—The texture is porphyritic; the glassy groundmass is in the main devitrified, is in some varieties spherulitic, and greatly exceeds the phenocrysts in volume. It is pink in thin section and originally was slightly vesicular, but most of the vesicles have been lined or filled with secondary quartz. The spherulites are smaller than those of rhyolites Nos. 1 or 5 and are not visible in

hand specimen. The phenocrysts are orthoclase, quartz, albite, oligoclase, mica, green hornblende, and magnetite. These resemble the phenocrysts in other flows described, though hornblende is more abundant than in the earlier rhyolites.

RHYOLITE No. 14.

Rhyolite No. 14 outcrops on the west slope of Rainbow Mountain, on which it lies conformably above rhyolite No. 13. It is composed of thin flows of green glass resembling rhyolite No. 12, alternating with spongy white or dense pink rhyolite flow breccia, in which the fragments are like the matrix. When viewed at a distance from a point west of Rainbow Mountain (Pl. III, *A*) this formation and rhyolite No. 12 appear as thin dark-green bands that contrast strongly with the other flows. The lower green layer, rhyolite No. 12, is almost entirely green glass, but rhyolite No. 14 contains more lithoidal material. This, however, is not conspicuous, and from a distance the formation appears almost homogeneous owing to the greater prominence of the green glass. The maximum thickness of rhyolite No. 14 is approximately 200 feet.

RHYOLITE No. 15.

Occurrence and distribution.—Rhyolite No. 15 occurs only on Rainbow Mountain and represents one or more flows which closely followed the eruption of rhyolite No. 14. It is made up of pink or white flow breccia containing fragments like the matrix and inclosing large flat bodies of green glass, of which the longer axes lie approximately in the plane of the flow. Some of these bodies are about 40 feet long and 10 feet thick. They are too small to be separate flows and are either an example of flow banding on a large scale or fragments of rhyolite No. 14 caught and buoyed up by the viscous moving lava, which later, upon solidifying, formed the white flow breccia. If this view of their origin is correct the blocks are now close to their source, for their flat shape, weight, and size would have prevented them from being carried far without breaking into smaller and more stable forms. The maximum thickness of rhyolite No. 15 is 175 feet and it dips steeply toward the east with the associated lavas.

Microscopical character.—The texture is porphyritic. The lighter-colored facies closely resembles rhyolite No. 11, though it is in most places less pumiceous. The groundmass is a devitrified glass and as a rule exceeds in volume the phenocrysts, which are quartz, oligoclase, orthoclase, mica, magnetite, and hornblende. In the more porphyritic facies the proportion of orthoclase to oligoclase is greater than in the more nearly aphanitic facies, which indicates that the groundmass is on the whole richer in alkalies than are the phenocrysts. The green glass contained in rhyolite No. 15 is similar to that of rhyolite No. 12.

RHYOLITE No. 16.

Rhyolite No. 16 is the youngest rhyolite exposed in the Bullfrog district. It outcrops on Rainbow Mountain, forming the summit and extending eastward to the saddle between this mountain and Black Peak. Another area, in contact with this one by faulting, occurs just north of the Montgomery-Shoshone mine, and its southeastern edge forms the hanging wall of the Montgomery-Shoshone fault in the Providence mine. A third outcrop occurs as a long strip of irregular width to the northeast of the Providence mine, where it is largely masked by talus from Black Peak. The maximum thickness of rhyolite No. 16 is about 400 feet. At the base of the formation is a flow of green glass of variable thickness, which is greatest at the summit of Rainbow Mountain. Above the basal flow is a light-colored rhyolite flow breccia, much of it cellular or spongy, which contains many blocks of green glass, ranging from less than 1 inch to more than 10 feet in diameter. The outcrop north of the Montgomery-Shoshone mine and also the one northeast of the Providence are of the upper light-colored variety, which at both places contains large bodies of green glass, a feature by which this formation may be easily distinguished from all rhyolites that precede rhyolite No. 12. Under the microscope, as in the field, the lower flow of green glass is similar in appearance to rhyolites No. 12 and No. 14. The upper flow breccia is like the light-colored flow breccia of rhyolite No. 15. Rhyolite No. 16 is conformable with the formations above and below it.

PLAGIOCLASE BASALT No. 5.

Plagioclase basalt No. 5 lies conformably above the latest rhyolitic formation (rhyolite No. 16) and is overlain by quartz latite. Its only outcrops are on the southern and western slopes of Black Peak. The thickness of the flow varies considerably; it reaches a maximum of about 60 feet one-fourth mile north of the Montgomery-Shoshone mine, but thins out rapidly northward, and disappears just south of the saddle between Black Peak and Rainbow Mountain. North of this saddle the basalt is wanting and the quartz latite rests directly upon rhyolite No. 16. The irregular upper surface of the flow suggests that the basalt was eroded before the eruption of the quartz latite, and further evidence of this is afforded by the presence of a thin bed of tuff containing fragments of basalt and rhyolite, which occurs only at one place about 800 feet S. 3° W. of the saddle between Rainbow Mountain and Black Peak. Owing to its very narrow distribution, this tuff is not represented on the map, but is included with the basalt. In the field and under the microscope basalt No. 5 resembles basalt No. 3, which is described on page 44. It probably represents a single lava flow which was extravasated upon a nearly level surface. Later it was tilted eastward with the associated flows.

QUARTZ LATITE.

Definition.—Quartz latite is a glassy or fine-grained (microcrystalline) rock, of which the silica content is between that of rhyolite and andesite. As a rule it is porphyritic. It contains orthoclase, plagioclase, usually oligoclase or andesine, quartz, and a small amount of one or more of the ferromagnesian minerals—dark mica, hornblende, and pyroxene. It is the volcanic equivalent of quartz monzonite and occurs as flows and dikes.

Occurrence and distribution.—Quartz latite forms the dark capping which gives Black Peak its name. It also forms the summit of the peak just east of Black Peak and, dipping eastward, nearly with the slope, it constitutes the ridge that descends from that peak to the flat. Northward from the saddle between Rainbow Mountain and Black Peak the base of the quartz latite rests upon rhyolite No. 16; to the south of this saddle it rests upon basalt No. 5, except at one small exposure about 800 feet south-southwest of the saddle, where a thin bed of tuff lies between the basalt and the quartz latite. The quartz latite is a flow about 250 feet thick.

General character.—The quartz latite is dark brown or nearly black and is in places glassy, especially near its base. Phenocrysts of feldspar are abundant, those of quartz less so. Nearly everywhere it contains mica, which is as a rule golden bronze. The base and to a less extent the upper part of the flow are vesicular. This flow is much fresher in appearance than basalt No. 5, upon which it sometimes rests, is not quite so dark in color, and may further be distinguished from the basalt by the greater abundance of dark mica foils.

Microscopical character.—The texture is porphyritic; the groundmass, which exceeds the phenocrysts in volume, is glassy, seldom devitrified, rarely spherulitic. It contains many laths of plagioclase which vary in length from 0.1 to 0.4 millimeter. In some sections the longer axes of the plagioclase laths are oriented in the same direction, suggesting the texture sometimes called trachytic. The larger phenocrysts are oligoclase, andesine, quartz, and biotite. Smaller ones of orthoclase, biotite, augite, ilmenite, magnetite, titanite, and apatite are also present.

An analysis of the quartz latite made in the Survey laboratory is given below. According to the quantitative system of classification the rock is toscanose. Its composition is very close to that of many quartz latites and of the dacite from McClelland Peak, Washoe, Nev.[a]

[a] Hague, A., and Iddings, J. P., Bull. U. S. Geol. Survey No. 17, 1885, p. 33.

Analysis of quartz latite (B. 172) from the top of Black Peak.

[George Steiger, analyst.]

SiO_2	63.34	H_2O+	1.16
Al_2O_3	15.46	TiO_2	1.53
Fe_2O_3	4.14	CO_2	None.
FeO	.39	P_2O_5	.22
MgO	.66	MnO	.04
CaO	2.01	BaO	.15
Na_2O	3.89	SrO	.03
K_2O	5.31		
H_2O-	1.89		100.22

TUFF No. 2.

In the saddle just east of the summit of Black Peak a bed of yellow, partly consolidated tuff, composed of very finely comminuted material, lies upon the quartz latite and separates it from the overlying quartz basalt. This bed, about 40 feet thick, is of well-stratified material, chiefly rhyolitic, and represents the accumulation of volcanic débris in a body of water which was probably of very slight extent. Since it contains little if any of the underlying quartz latite it may be a volcanic ash that fell directly into the water and was not washed from the surrounding land. This outcrop is all that remains of tuff No. 2, for to the east it is in contact by faulting with quartz latite, which forms the summit of this ridge to the east. Tuff No. 2 dips eastward at a steep angle with the associated lava flows.

QUARTZ BASALT.

Occurrence and distribution.—The latest lava flow exposed in the Bullfrog district is a quartz-bearing basalt which lies above the youngest tuff and forms the summit of the spur just east of Black Peak. To the east of this spur the quartz basalt has been depressed by a north and south fault which brings it into contact with the quartz latite, so that only a very small body of it remains. The quartz basalt dips eastward with the other lavas and has a minimum thickness of about 70 feet.

Microscopical character.—The quartz basalt is dark grayish brown and differs but little in color from the quartz latite; the groundmass is not so dense and glassy, the phenocrysts are larger, and those of quartz are more abundant. Olivine is not visible in hand specimens. The microscope reveals a dark, glassy, devitrified groundmass thickly dotted with magnetite and augite and in places slightly spherulitic. It contains many small laths of labradorite and andesine, as a rule about 0.4 millimeter long, the arrangement of which is slightly trachytic. Phenocrysts of andesine, oligoclase, orthoclase, and embayed quartz are present, and smaller ones of olivine, augite, mica, and magnetite. Rarely there is a phenocryst of hornblende. Olivine

is almost completely altered to serpentine; otherwise the rock is fresh. Quartz is especially abundant for a rock containing olivine, but is unquestionably original. An analysis of the quartz basalt made in the Survey laboratory from a specimen taken from the knob just east of the summit of Black Peak is given below. According to the quantitative system of classification this quartz basalt is hartzose, which is a type rather more siliceous than the usual quartz basalt. A quartz basalt from Lassen Peak, California, described by J. S. Diller,[a] has only a little less silica.

Analysis of quartz basalt (B. 314) from the summit of the small knob 400 feet east of the summit of Black Peak.

[George Steiger, analyst.]

SiO_2	59.72	H_2O+	1.38
Al_2O_3	14.63	TiO_2	.95
Fe_2O_3	3.40	CO_2	1.12
FeO	2.37	P_2O_5	.40
MgO	2.69	MnO	.10
CaO	6.55	BaO	.04
Na_2O	3.28		
K_2O	3.33		100.68
H_2O-	.72		

Age and origin.—The quartz basalt represents a single flow and may at one time have covered a considerable portion of this area. Its eruption probably occurred soon after that of the quartz latite, and so far as is shown in the Bullfrog district this eruption was the last that flowed over the surface, though some of the basalt dikes may represent volcanism of still later age.

INTRUSIVE ROCKS.

RHYOLITE PORPHYRY.

A relatively large intrusive mass of rhyolite porphyry with very irregular crosscutting boundaries occurs west of Box Canyon on the south slope of the low hill (elevation 4,280+ feet) 6,000 feet N. 86° E. of the Original Bullfrog mine, where it cuts through rhyolite No. 1. When fairly fresh it is gray or grayish green, but when weathered or much altered it is brown. It contains phenocrysts of feldspar, quartz, and biotite. The feldspar phenocrysts are white or pale green and where the rock has disintegrated perfect crystals up to one-fourth inch long may be picked out of the sand. The quartz phenocrysts are clear, colorless, or milky white. The biotite flakes are much decomposed. Under the microscope the groundmass is seen to be fine grained, but at most places it is more crystalline than the groundmass of rhyolite No. 1 and it is at no place glassy or spherulitic. It is composed of feldspar, quartz, apatite, and zircon, thickly dotted

[a] Bull. U. S. Geol. Survey No. 148, 1897, p. 196.

with chlorite, magnetite, and serpentine. In some sections it contains minute lath-shaped crystals of plagioclase, the orientation of which suggests the trachytic texture. The phenocrysts are orthoclase, albite, oligoclase, chloritized biotite, titaniferous magnetite, and altered forms suggesting a derivation from hornblende. The rhyolite porphyry in general appearance and in mineral composition more closely resembles the crystalline facies of rhyolite No. 1 than any of the other rhyolites, and it may be an intrusive contemporaneous with upper flows of that formation.

West of the Big Bullfrog mine and on the east slope of the low hill (elevation 4,020+ feet) in the southwest corner of the area mapped a rhyolite porphyry dike trending N. 20° E. cuts the crystalline schists. It is light gray or yellowish gray and contains smaller phenocrysts than the rhyolite porphyry intrusive west of Box Canyon. Under the microscope the groundmass is seen to be composed of quartz, orthoclase, and iron oxides, and it is rather more coarsely crystalline than the groundmass of the other rhyolite porphyry intrusive. Chlorite is not abundant and hornblende was not noted. The phenocrysts are quartz, orthoclase, and albite.

PLAGIOCLASE BASALT DIKES.

Occurrence and distribution.—Within the area included in the special map about forty plagioclase basalt dikes cut the Tertiary lavas. These vary in width from a few feet to nearly 100 feet and some of them may be traced continuously for 1,000 yards. At most places they occur along fault fissures and consequently their general trend is from north to northeast, and their dip is as a rule west or northwest. Some of them are undisturbed and adhere to the rocks which they cut, but by far the larger number are shattered and crushed, and their sides show striæ and slickensides, indicating that movement has occurred since intrusion. Many of them are discontinuous, thinning out and ending, to reappear along the same strike. This lack of continuity is probably due partly to incomplete filling during intrusion and partly also to faulting after the intrusion, with slight divergences between the planes of faults and dikes. The dikes are less resistant to weathering than the rhyolite, which they cut, and consequently exposures of them are not prominent. At very many places their presence is marked only by a ravine or slight depression, along the bottom of which there is a thin and interrupted streak of basalt débris.

General character.—The basalt dikes closely resemble the basalt flows and can not ordinarily be distinguished from them in the field by lithologic features alone. Both have vesicular and dense facies and it is in some cases impossible to determine whether or not a given body of basalt is intrusive unless its contact with other rocks is visible.

On the southwest slope of Ladd Mountain, for example, is a branching basalt dike about 2 feet wide which is undisturbed by faulting and which cuts through rhyolite No. 6. At the contact this dike is vesicular and glassy, while near the center it is almost free from vesicles and is microcrystalline. Vesicular facies of plagioclase basalt also occur in dikes at many other localities, and it is possible in almost every instance to find some vesicular fragments in the basalt débris which marks the presence of a dike in a ravine.

Microscopical character.—The dikes are glassy or microcrystalline and contain many small laths of plagioclase, whose average composition is that of labradorite. Either olivine or its decomposition product is invariably present. Augite occurs in most specimens and in some is abundant. Small grains of titaniferous magnetite and crystals of apatite are numerous. Serpentine, chlorite, and calcite are present in most sections as alteration products of the ferromagnesian minerals. On account of their proximity to planes of movement that are or have been channels for circulating water, most of the dikes are more altered than the basalt flows.

Age and relation to flows.—There is no evidence concerning the age of those dikes that do not follow fault planes, except that they are younger than the lava flows that they cut. Basalt dikes cut rhyolite No. 10 and older formations, but they have not been discovered in the younger rhyolites. All the basalt dikes may not be of the same age, and it is probable that they were connected with basalt flows and fill the channels through which these issued. The age relations between dikes and faults are further discussed on page 72.

LEUCITE BASANITE.

Definition.—The essential constituents of leucite basanite are leucite, feldspar, and olivine, though nepheline, pyroxene, magnetite, biotite, apatite, and other minerals are often present.

Leucite basanites are nearly related to leucite basalts in composition but contain feldspar in addition to leucite. In the preliminary account of the Bullfrog area[a] the leucite basanite was referred to as leucite basalt, but examination of material collected subsequent to the date of that report shows that in the more crystalline facies considerable plagioclase is present.

Occurrence and distribution.—The leucite basanite of the Bullfrog area is known to outcrop at only three places: On the flat west of Rainbow Mountain, on the flat north of Montgomery Mountain, and on the south slope of the hill (elevation 3,580+ feet) about 4,000 feet south of Beatty. In each of these places the leucite basanite is partly or completely surrounded by plagioclase basalt and its

[a] Ransome, F. L., Garrey, G. H., and Emmons, W. H., Preliminary account of Goldfield, Bullfrog, and other mining camps in southern Nevada: Bull. U. S. Geol. Survey No. 303, 1907, p. 49.

relations to the other igneous rocks could not be determined. At two of these localities the leucite basanite occurs at the horizon of basalt No. 4, but the outcrop south of Beatty is at the horizon of basalt No. 2. If the leucite basanite is intrusive it may all be of the same age; but if all the masses are parts of lava flows their eruptions were separated by the extrusion of a considerable thickness of rhyolite and plagioclase basalt. No dikes of leucite basanite have been discovered in the rhyolites and it can not be widespread, for the examination of 60 thin sections of the basaltic rocks showed leucite in three only. A number of pebbles were examined from rhyolite No. 11, the overlying flow breccia, and all were found to be plagioclase basalts. But since it is impossible to distinguish the plagioclase basalt and the leucite basanite in the field, small masses of the latter may have been overlooked and mapped as basalt.

Microscopical character.—The leucite basanite is a black, nearly aphanitic rock which in fresh specimens shows phenocrysts of olivine more or less altered to iron-stained decomposition products. The microscope reveals the following minerals, approximately in the order of their abundance: Augite, olivine, leucite, magnetite and ilmenite, plagioclase, nepheline, biotite, apatite, and zircon. The microcrystalline groundmass is composed of augite, leucite, and nepheline thickly dotted with small crystals of biotite, magnetite, ilmenite, and serpentinized olivine. Apatite is for the most part included in leucite. In some of the leucite crystals the longer axes of the included apatite crystals are oriented parallel to the boundaries of leucite. In the more crystalline varieties small laths of labradorite are present in considerable quantities. The phenocrysts are augite and olivine. Calcite is usually present and olivine is partly or completely altered to serpentine.

An analysis of the leucite basanite made in the Survey laboratory is given on page 60. The norm of this rock, calculated according to the method proposed by the quantitative system of classification, is also given. The principal differences between this theoretical composition and the mode or actual composition of the rock are as follows: Orthoclase is rare or wanting in the mode and there is enough leucite (6.10 per cent) to account for all of the potash present; there is a little less nepheline and a little more albite than is shown by the mode; the pyroxene is probably aluminous, for corundum is absent in the mode; a little biotite and secondary calcite are present.

In the scheme for the classification of igneous rocks proposed by Cross, Iddings, Pirsson, and Washington, this rock belongs to the portugare order, docalcic rang, and persodic subrang. The rang and subrang have not been named. Rocks of this subrang have been analyzed from various European localities but have not hitherto

been reported from the United States. It is suggested that amargase and amargose (from the Amargosa Desert) would be appropriate names for the rang and subrang respectively.

Analysis of leucite basanite 2,000 feet southwest of summit of Rainbow Mountain (B. 107).

[George Steiger, analyst].

SiO_2	43.62	ZrO_2	0.02
Al_2O_3	12.73	CO_2	.63
Fe_2O_3	4.89	P_2O_5	.82
FeO	4.10	SO_3	None.
MgO	9.37	S	None.
CaO	11.62	MnO	.12
Na_2O	2.96	BaO	.16
K_2O	1.30	SrO	.14
H_2O-	1.91		
H_2O+	3.94		99.79
TiO_2	1.46		

NORM.

Orthoclase	7.78	Apatite	2.02
Albite	15.20	Diopside	31.05
Anorthite	13.07	Olivine	7.12
Nepheline	5.40	H_2O, etc	6.50
Corundum	1.63		
Magnetite	7.19		99.70
Ilmenite	2.74		

SUMMARY OF THE TERTIARY ERUPTIONS.

In Tertiary time, probably in the early Miocene, rhyolite No. 1 was erupted in two or more flows, separated by an interval long enough for the formation of 30 feet of limestone. Little is known of the surface upon which rhyolite No. 1 was poured out, for the base of the volcanic series is not exposed; but it is unlikely that lava of any considerable thickness underlies the oldest visible rhyolite formation. Rhyolite No. 2 flowed out upon the nearly level surface of rhyolite No. 1, but before its eruption there was an extrusion of basalt that is not exposed in the area mapped. There was also an interval of quiescence and erosion long enough for disintegration and weathering of the basalt, for the surface upon which rhyolite No. 2 flowed was covered with partly rounded débris of basalt and rhyolite.

The eruption of basalt No. 1 followed that of rhyolite No. 2, probably with little erosion between. It was a thin flow of small extent and was followed by the successive eruptions of rhyolites Nos. 3, 4, 5, and 6, each of these formations being fairly uniform and persistent rhyolite. No. 3 probably consists of more than one flow, and this is certainly true of rhyolite No. 5, which in some places contains two basal contact glasses. Rhyolite No. 6 was followed by the eruption of basalt No. 2, which is a little thicker than basalt No. 1 and covers a greater area.

Rhyolite No. 7 followed basalt No. 2. There was a little erosion and weathering between, but this was apparently of such character as to leave only slight depressions or very gentle slopes, for the small and nearly uniform thickness of rhyolite No. 7 shows that it flowed upon an even surface. It was followed by rhyolite No. 8, with little or no intervening erosion. The two flows are locally separated by the basal glassy contact of rhyolite No. 8, which, above the glass, is very uniform in texture and appears to represent a single flow. Basalt No. 3, thin and very local in occurrence, followed rhyolite No. 8. It was perhaps formerly much more extensive, for the succeeding rhyolites Nos. 9 and 10 contain many angular basalt fragments, which were apparently picked up as they flowed over the surface. The very persistent basal glass of rhyolite No. 10 shows that these two formations are separate flows.

Basalt No. 4, which followed rhyolite No. 10, is the thickest and most persistent of all the basalt flows. After its eruption there was a period of relative quiescence, during which a basin formed, into which the débris from the surrounding country was washed. But there was some volcanic activity while the tuff was deposited, for at one place it contains a thin bed of rhyolite flow breccia. Following the formation of the tuff, rhyolites No. 11 to No. 16 were erupted, probably with very short intervals between. These are pink and white flow breccias, alternating with green or brown glass. They are all much the same in composition and of fairly uniform thickness. They were apparently once more extensive, but have been eroded from the larger part of the area. Rhyolite No. 16 was followed by basalt No. 5, and this by an eruption of quartz latite. A thin bed of stratified tuff was deposited upon the quartz latite, and upon that quartz basalt was extravasated. Some of the lavas, probably before all were erupted, were intruded by quartz porphyry, plagioclase basalt, and probably by leucite basanite. Exposures of intrusive rocks are confined to lavas older than rhyolite No. 11, and it is possible that most of the intrusive bodies were formed before this rhyolite was erupted.

The intrusive rhyolite porphyry is closely related to the rhyolites in composition and may represent some of the rhyolite lava that ascended to the surface through channels which the porphyry now occupies; but it seems unlikely that any considerable portion of the rhyolite magma ascended by these supposed conduits, for there is no pronounced metamorphism of the rocks in their vicinity and the dip or thickness of the lava beds do not appear to be related to the intrusive masses in any way that suggests the latter as a source. The principal sources of the rhyolite flows have not been identified. They may be covered by later lavas or may be buried beneath the wash of the desert flats. The nearly uniform thicknesses of most of

the flows shows that they spread over a flat surface; the beds that do thin out are not thickest at any common geographic point that might be assumed as their source. Some of them are thickest in the eastern part of the district, others in the western part. The lavas may have poured out through numerous conduits.

Some of the basalt dikes may fill channels through which some of the basalt flows reached the surface. The rocks have the same composition and differ very little in crystallinity of groundmass. Many of the dikes, however, are clearly younger than the beginning of the faulting and the tilting by which all the flows are affected.

The many flows of basalt interbedded with the many flows of rhyolite show that highly acidic eruptions alternated with basic eruptions. The flows followed one another so closely that it is improbable that each flow represents a new differentiation product from a common magma. It is more likely that the two kinds of lavas were supplied from different sources through alternately opened vents.

There is no evidence of tilting and faulting during the period of lava flows. The fact that the basalt dikes do not occur in rocks as recent as rhyolite No. 11 suggests that they may be in the main older than this flow; since, however, so many of the dikes are obviously related to the fault systems and since these faults cut all flows, the absence of dikes from rhyolite No. 11 and from younger flows may be merely a feature of areal distribution.

QUATERNARY ALLUVIUM.

The youngest formation in the Bullfrog district is the so-called wash, which covers a large area and is composed of sand, gravel, angular detritus, and large bowlders. It merges with the talus of the slopes and occupies the depressions between the mountains. Only the upper portion of the wash is exposed, for there are no deep canyons in it. The Amargosa shaft, sunk at a point 3,100 feet S. 15° W. of the summit of Ladd Mountain to a depth reported to be 330 feet, is entirely in wash. If the slope of Ladd Mountain were projected it would pass only a little more than 100 feet below the bottom of this shaft. It thus appears that here, at least, the slope of the rock surface under the wash is nearly or quite as steep as the average slopes of the mountains. The mountainous area once had greater relief than at present and the low places have been gradually filled up with waste from the hills. This process is still going on through the agency of many small, intermittent streams, as is the case in most desert countries.

The fragments that compose the wash are from all the formations exposed; they range in size from dust to bowlders over a foot in diameter. Some of them are subangular; others are imperfectly rounded, but very few appear to have been transported any great distance. In many places the dust in the wash is consolidated, much as adobe bricks are hardened in the sun.

GEOLOGIC STRUCTURE.

OUTLINE.

The preceding sections discuss the characteristics of the various rock formations, their distribution, and their sequence. This section on geologic structure treats of the deformation by faulting and tilting which gave the rocks their present attitudes.

After the eruption of the quartz basalt, which is the latest lava flow represented on the geologic map, and near the close of the Tertiary or in early Quaternary time, the various lavas and tuffs lay nearly horizontal, one above the other. There are slight erosional unconformities between some of the formations, but the series throughout the area included about the same members, so that if a number of drilled holes, each a mile or more deep, had been put down at various places, before the country was faulted and tilted, each would have encountered approximately the same succession of volcanic materials. The present distribution of the rocks is very different, for flows which are among the earliest cap some of the highest hills, and at several localities the oldest rhyolite outcrops at higher elevations than the latest lava flow, the quartz basalt.

TILTING AND FAULTING.

TERMINOLOGY.

The displacement of strata on one side of a fissure with reference to those on the other side is called a fault. Most fault fissures are inclined and the vertical angle by which a fault plane departs from a horizontal plane is called the dip. The direction of a horizontal line in the fault plane is the "strike" of the fault. When the hanging wall appears to have dropped with reference to the foot wall the fault is a "normal" fault, and when the foot wall appears to have dropped with respect to the hanging wall the fault is "reverse." All the faults in the Bullfrog district, so far as known, may be classed as normal faults.

Many faults are marked by slickensides, which are smooth, polished surfaces resulting from movement along the fault plane. The slickensided surfaces as a rule are scratched or striated by the grooving action of harder particles or projecting points as one wall moves upon the other. These striæ show the direction of relative movement of the walls.

A "fault zone" consists of two or more nearly parallel fault fissures with thin sheets of country rock between them. In places intersecting fractures connect the main fissures and these cross fractures may be so numerous that the rock in the fault zone is much fractured or is crushed.

The usage of geologists is not uniform regarding the nomenclature of the elements of faults. J. E. Spurr[a] first proposed a terminology to be used where data are complete, but when broad areas are described the facts obtainable are rarely or never adequate to define every detail of all the fault movements. As a rule the structure is expressed by vertical sections, taken where exposures are best and rarely at right angles to the strike of all the faults shown. Sections used in text-books to illustrate the elements of faulting are, as a rule, drawn at right angles to the strike of the fault plane.

In the study of the structure of tilted beds that have been faulted three sets of planes are to be considered: (1) The top or base of a bed or some similar horizon, (2) the plane of the fault, and (3) the plane of the section under discussion. Where the bed is faulted by a straight fault plane there are two lines of intersection formed by the fault plane and the upper or lower surfaces of the separated portions of the bed. Ordinarily these two lines are approximately parallel. Unless the strike of the fault is the same as the strike of the beds the two lines of intersection between the upper or lower surface of the bed and the fault are inclined to a horizontal plane. Sections drawn across the strike of the fault cut these lines at two points which may be used as datum points from which the apparent horizontal, vertical, and inclined elements of a fault, as shown in the section, are calculated. The position of these two points with respect to each other is different in vertical sections drawn in different directions through the same fault. It is convenient to have terms that apply only to a given section under discussion, without reference to a plane at right angles to the fault plane and without regard to the origin of the fault movement. This will be accomplished by prefixing the adjective "apparent" to the names of various elements. Description of what may be called the geometry of faulting is thus kept distinct from inference as to the cause of the movements.

"Apparent vertical displacement" is used in this report to designate the vertical distance between or the difference in elevation of two points that are the intersections of the two separated portions of a bedding or similar datum plane with the fault and that are in the plane of a vertical section chosen at random. This usage is illustrated by figure 6, where the apparent vertical displacement is measured by dropping a vertical line *ab* from the higher point *a* to a horizontal line passing through the lower point *c*, both lines being in the plane of the section under discussion. The apparent vertical displacement would be represented by *ab*, whatever angle the section makes with the strike of the fault. As thus used the term has definite meaning only for the section under discussion.

[a] Geology of Aspen mining district, Colorado: Mon. U. S. Geol. Survey, vol. 31, 1898, p. 251.

The term "apparent horizontal displacement" is used in this report to designate the horizontal distance between the intersections of two faulted parts of a bedding or similar plane with the fault plane, in any vertical section. The apparent horizontal displacement is represented in figure 6 by *cb*, which is the horizontal line drawn from the lower point of intersection *c* to the perpendicular from *a*, the upper point of intersection of the stratum with the fault plane, all lines being drawn in the plane of the section.

Similarly, the distance (*ac* in the diagram) between the faulted edges of a datum plane, measured along the line common to the plane of the fault and the plane of a section under discussion, may be called the "apparent throw" and will coincide with the real throw only when the section described makes a right angle with the fault plane.

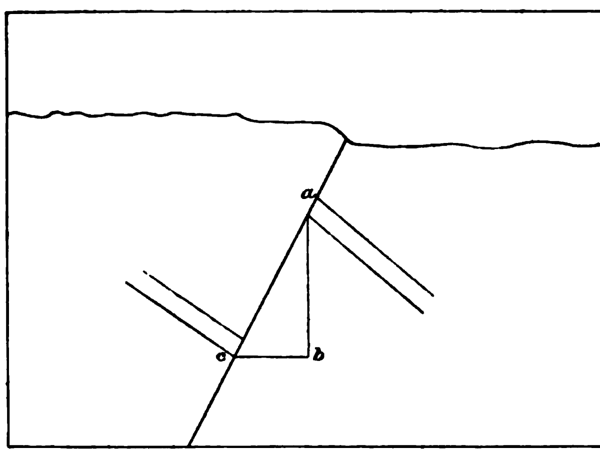


FIGURE 6.—Diagram illustrating apparent vertical and horizontal displacements. See text for explanation.

According to Spurr,[a] "offset may be used to designate the perpendicular distance between the intersection of corresponding planes in the two parts of any faulted body with a horizontal plane, such as the earth's surface may be considered to be, the planes being projected for the purpose of measurement if necessary." Where such a projection is necessary the parts of the planes are said to be offset with "gap," and where a line representing the offset intersects a faulted stratum or other datum plane at two places without such projection of the bed the stratum is said to be offset with "overlap."

CRITERIA FOR THE RECOGNITION OF FAULTING.

The original attitude of sedimentary rocks is horizontal, or nearly so. If water-stratified rocks are laid down upon a steep slope the

[a] Op. cit., p. 162.

thickness of the bed will vary and the base may have a steep inclination, but the bedding planes will in most cases be approximately horizontal. Similarly, a molten lava flowing over a surface first fills the deepest places and consequently is thickest there. Most of the lava flows here described are of nearly uniform thickness and hence flowed on a nearly level surface. Where a lava is highly viscous a considerable initial inclination of the upper surface of the flow may also result, and, consequently, this surface may dip steeply even when it has not been deformed by movement; but in that case the thickness of the flow usually varies greatly. Lava moves while it is cooling, and before it solidifies may become highly viscous and thus develop flow lines which are steeply inclined when solidification takes place. Accordingly, flow lines do not show the original attitude of the lava beds and can not be depended on for measurement of dip and strike, but the dip and strike may be safely measured on the bedding planes of water-laid tuffs between the flows, or along contacts between basalts and rhyolites of comparatively uniform thickness or between rhyolites of different color or composition. The occurrence of the brown contact glass at the base of several of the rhyolites in the area here discussed is of great assistance in determining the attitude of the flows.

In many of the mountains of the Bullfrog district, especially when viewed from the south, as in Plate II, the flows may be observed dipping below the surface at steep angles. Sutherland Mountain and the south slope of Busch Peak are exceptions, for in these the dip is very gentle. While the strike of the formations varies considerably in different fault blocks, the average is approximately north and south and the average dip is about 27° E.

The lavas are shattered, jointed, and traversed by small fractures or parting planes, which trend in almost every direction. Some of these have the direction of flow lines; others strike approximately with the flows; some are nearly parallel to faults, while others are at about right angles to them; still others apparently make large angles with all other structural features. Altogether they form a most irregular network. None of the rocks that are younger than the crystalline schists have been closely folded and there is little or no suggestion of even gentle arches or troughs.

Owing to the rugged character of the topography, the absence of vegetation, and the abundance of prospect pits in this district, exposures are unusually good and many of the faults may be traced without interruption for considerable distances. Where associated flows contrast strongly in color, as the basalt or the dark-glass flows with the light-colored rhyolites, faults may be recognized a mile or more away. Examples are the Saddle fault, northwest of Rl te (see Pl. VIII, *A*), the fault which crosses the glass flow on th est

A. SADDLE BETWEEN SUTHERLAND MOUNTAIN AND BUSCH PEAK, FROM THE SOUTHEAST.

Showing the Saddle fault with downthrow on right. The dark flow of basalt No. 2 is cut obliquely by the Denver fault at the right of the illustration.

B. FAULT ON SOUTH SLOPE OF HILL SOUTH OF SAWTOOTH MOUNTAIN.

spur of Burton Peak, and the faults on the south side of the mountain south of Sawtooth Mountain (Pl. VIII, *B*); these faults are among the most conspicuous features of the near landscape around Rhyolite. Where flows closely resemble one another it is very difficult to trace faults, but fortunately in many such cases basalt dikes or débris of basalt marks the fault plane. An example is the northern portion of the Hobo fault, on the hills northwest of the Las Vegas and Tonopah Railroad station. Along a part of its length rhyolite No. 8 forms both the hanging and the foot wall, and abundant and almost continuous basalt débris along this fault plane becomes a useful guide. When both hanging and foot walls of a fault are the same rock and basalt is absent, it is difficult or impossible to trace the faults accurately. These are the conditions along that portion of the Denver fault on Busch Peak north of the outcrop of basalt No. 2, which it displaces. Wash covers

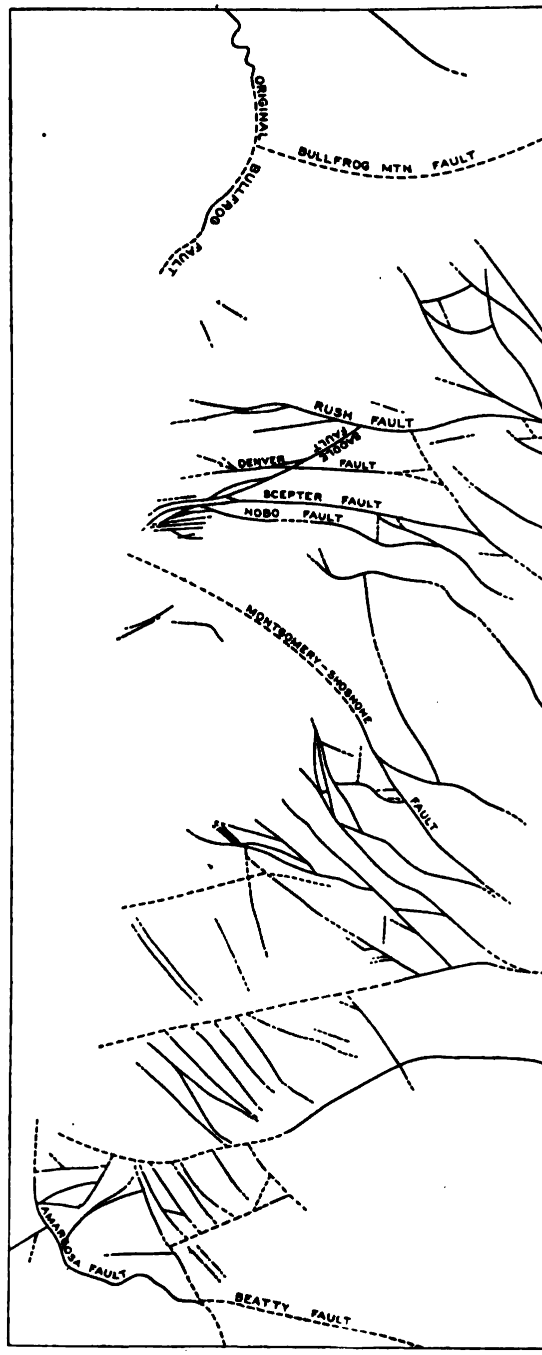


FIGURE 7.—Plan of the principal faults in the Bullfrog district.

up a large number of faults; some partly, others completely. For example, the structure and succession of Ladd and Montgomery mountains show that a fault striking northwest, with a vertical displacement of many hundred feet, occurs between the two mountains, but no part of its outcrop is exposed. The Montgomery-Shoshone fault can be traced accurately along a part of its course, but after it passes into the flat southwest of the Polaris mine only its approximate location can be determined. Since the beds which form Bonanza Mountain have been depressed with respect to those which form Ladd

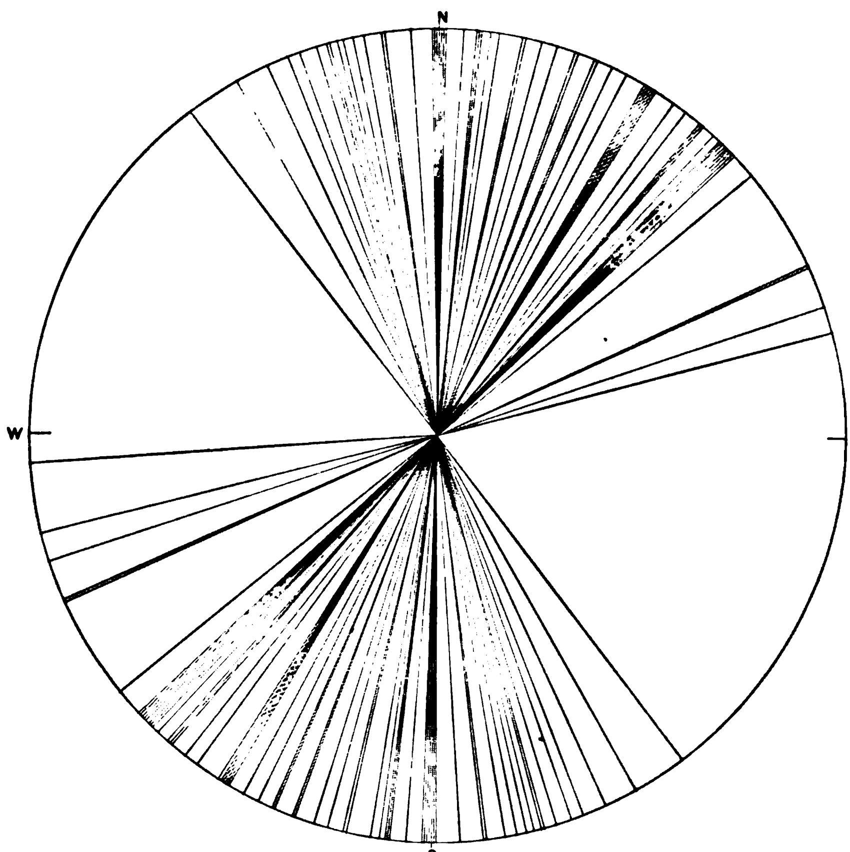


FIGURE 8.—Diagram showing strikes of faults.

Mountain by about as much as the vertical displacement of the Montgomery-Shoshone fault, it is certain that this fault, or one with approximately equal throw, passes under the wash somewhere between the two mountains.

STRIKE, DIP, AND COORDINATION OF FAULTS.

Nearly 100 faults have been recognized in the area shown on the map (Pl. I, pocket). Some extend almost across the area, and

others are short. (See fig. 7.) There are two fairly well defined fault systems, one striking nearly north and south and the other striking N. 30° to 50° E. A number of faults, however, do not fall into either system. Among these are several faults concealed by wash, which probably strike northwestward. The courses of 65 faults, including all the more important ones of which the strike is clearly shown, are platted in figure 8. It is worthy of note that the west-northwest and east-southeast octants of the circle are free from faults—that is, none of the faults platted strikes more than 45° west of north. Most of the fault planes dip westward or northwestward. In figure 9 the dips of 65 faults are platted through a common center, and of these only 16 dip eastward. The average dip of the faults platted is 62°. All of the faults dip 35° or more, with the exception of the Original Bullfrog fault and the Amargosa fault,

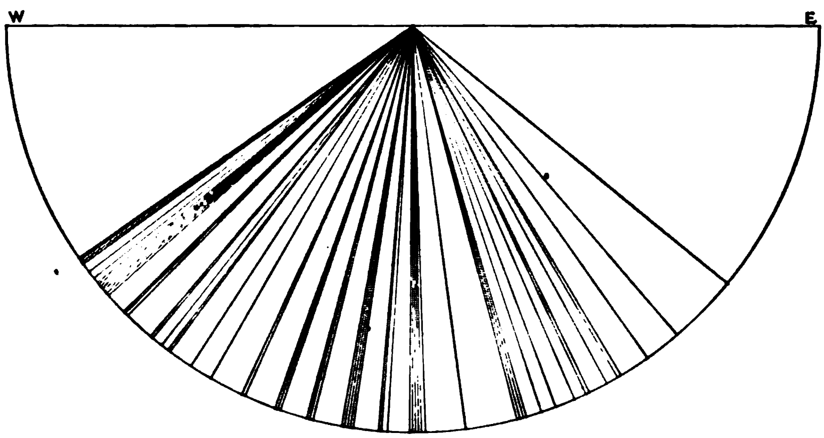


FIGURE 9.—Diagram showing dips of faults.

which at some places appear to have a very flat dip. These are not platted in figures 8 and 9. The average throw of the westward-dipping faults is greater than the average throw of the eastward-dipping faults.

CHARACTER OF FAULTS.

All of the faults for which sufficient data for classification are at hand are normal—that is, the hanging wall appears in every case to have been depressed. The fault fissure along which the ore body of the Denver mine occurs appears at first glance to be an exception. On level 3 the fissure dips toward the east; at this point both hanging and foot walls consist of rhyolite No. 5 and it is impossible to determine which wall has gone down. On the south slope of Busch Peak, at the horizon of basalt No. 2, the west wall very clearly has been depressed. This would imply that the fault is reverse, provided that it continues to dip east; but the straight outcrop over a diversified topography

shows that this portion of the Denver fault is vertical. The Saddle fault, of greater throw than the Denver fault, makes an intersection with the latter between the Denver mine and Busch Peak, so that there are four blocks formed by the cross faults. If the Denver fault and the Saddle fault were formed at the same time, it is highly probable that each of the four blocks formed at the intersection moved independently, so that the east or foot wall may have dropped at the Denver mine, while the west wall dropped at Busch Peak. Thus the Denver fault may be normal at both places.

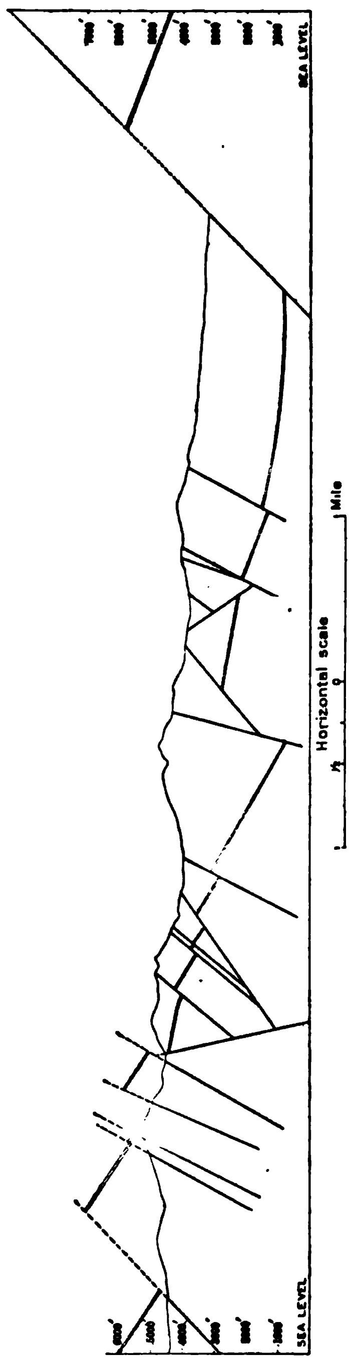


FIGURE 10.—Diagram illustrating displacements along section A-A', Plate I.

VERTICAL DISPLACEMENT OF FAULTS.

The vertical displacement of the faults, measured in a plane at right angles to the strike, varies from 2 or 3 feet to more than a mile. In figure 10 rhyolite No. 7 has been platted in section along the line A–A' on Plate I, the section being extended both eastward and westward a little beyond the boundaries of the area mapped. Where older flows outcrop, rhyolite No. 7 has been placed in the position which it very probably occupied before it was eroded, and where younger flows outcrop it has been platted below them, at a distance equal to the average thickness of the elsewhere intervening formations. This figure shows diagrammatically the apparent vertical displacement of the faults. It is to be noted that the faults of greatest apparent vertical displacement are the Beatty fault and the Bullfrog Mountain fault and that the Montgomery-Shoshone and Rush faults also have considerable apparent vertical displacement. The sum of the apparent vertical dis-

placements of all the west-dipping faults which this ection crosses is 12,500 feet, and the sum of the apparent vertical displacements of the east-dipping faults is 1,250 feet. The difference is 11,250 feet, and from inspection of this figure it appears that this amount of depression toward the west has resulted from faulting. Section A–A is further discussed on page 81.

Since the faults are all normal and figure 8 shows the dip of faults plotted through a common center, this figure also shows the prevailing direction of throw. While 16 of the 65 faults dip eastward, the throw of all but three of these is very small. The great downthrow by faulting is in the main toward the west.

STRIATIONS.

Striations or grooves on slickensided surfaces along fault planes are made by hard particles or hard projecting points of rock rubbing against softer rock. They show that one or the other wall has moved in one of two opposite directions.[a] Where there has been more than one movement along a fault plane the striæ formed by the first are likely to be erased by the last, and so those remaining, as a rule, record only the latest movement. Slickensided surfaces with two or more sets of superposed striæ have been observed, however, in other places; for example, in the Georgetown district, Colorado. Where hard particles formerly projected from one of the walls these are likely to have been worn asymmetrically, and the most worn side in this case should be the side representing the direction from which the opposite wall moved with respect to the wall in which the worn particle is embedded. The application of this criterion in the Bullfrog district is not very conclusive, however, owing to the slight differences in the hardness of the rocks. Striations are abundant, however, and a great many of these pitch at angles up to 70°. The average inclination of the striæ observed is about 60° from the horizontal, showing that the element of lateral movement was important. Lateral movement is further discussed on page 85.

RELATIVE AGES OF FAULTS AND FLOWS.

The quartz basalt which outcrops just east of the summit of Black Peak is the latest lava flow represented in the Bullfrog area. This flow is faulted about 150 feet by a fault which is joined by the Steinway fault and which ends at the Montgomery-Shoshone fault. Thus this fault appears to be not later than the Montgomery-Shoshone fault and there is nothing to show that practically all of the faulting did not occur after the extrusion of the quartz basalt. If any con-

[a] This is speaking in terms of one wall with respect to the other, for the scientists studying the results of the San Francisco earthquake found that the faulting movement was not confined to the movement of a single wall, but that both walls moved from their former positions, though in opposite directions.

siderable faulting occurred during the interval between the extrusion of rhyolite No. 1 and the quartz basalt, at some place in this area of exceptionally good exposures lava flows should be found covering the earlier faults or in flow contact with fault scarps. Further, such faulting, if accompanied by great displacement, would give a great variation in the thickness of succeeding flows and much of the geologic column would almost certainly be wanting above the higher fault block. The nearly uniform thickness of each flow and the persistence of most of them indicate that they suffered little displacement by faulting during the period of extrusion.

RELATIVE AGES OF FAULTS AND DIKES.

It is clear from an inspection of the geologic map (Pl. I) that the basalt dikes and the fault systems are very intimately connected. The determination of the relation between the intrusion of the dikes and the maximum displacement along the fissures is not, however, so easy as might at first glance appear. The true solution of the problem must reconcile the following facts: (1) No dikes have been found in any formation younger than rhyolite No. 10. (2) The greater number of the dikes occur along the fault fissures. (3) The principal faulting has displaced all of the flows, including those younger than rhyolite No. 10. (4) A very few of the dikes are adherent to both walls, are not traversed by a plane of movement, and consequently are of later age than any of the displacement at that place. On the other hand, the erratic and disconnected outcrops of dikes along many other faults, together with their slickensides, show that there has been much faulting since the intrusion of the dikes.

The amount of crushing and slickensiding along a fissure is not always proportional to the amount of displacement which has occurred between the separated ends of a formation. It is not uncommon to find very smooth, well-defined slickensides and one or both of the walls greatly crushed where the displacement has been very slight. On the other hand, great movement may take place along a plane no thicker than a knife blade and the rocks on either side be not greatly shattered.

It is necessary to conclude that the plan of the present fault systems was outlined by fissures before the intrusion of the dikes. It is conceivable that this initial fissuring took place not later than the eruption of basalt No. 4, that the dikes were then injected, and that consequently the main displacement along the fissure systems and dikes took place some time after the dike intrusions. Another view is that the dikes are younger than any of the flows and were intruded while the main faulting was in progress or after it had been effected.

The first view, which we are inclined to favor, is supported by the absence of dikes from formations younger than rhyolite No. 10

and by the discontinuous and disturbed conditions of the dikes. Further, the vesicular character of the dikes indicates that they formed under slight pressure and where gases could escape. They are therefore presumed to have formed before the hundreds of feet of lavas succeeding rhyolite No. 10 had been extravasated. The second view, regarded as a little more probable by our colleague, Mr. Ransome, is supported by the coincidence of dikes and faults and the absence of any considerable offsetting of the dikes by cross faults. He attaches less weight than do we to the absence of dikes from the younger flows, since this may be an accident of regional distribution, and he considers the disturbed condition of many of them as due to minor movements, subsequent to the great faulting. The problem is apparently not susceptible of definite solution under present conditions, and the two views given are to be taken rather as representing merely slight differences of opinion in regard to the comparative value of different lines of evidence than as the expression of firmly held conclusions.

EROSION SINCE FAULTING.

Figure 4 represents in a general way the position and distribution of the flows before deformation. After faulting, the same flow in

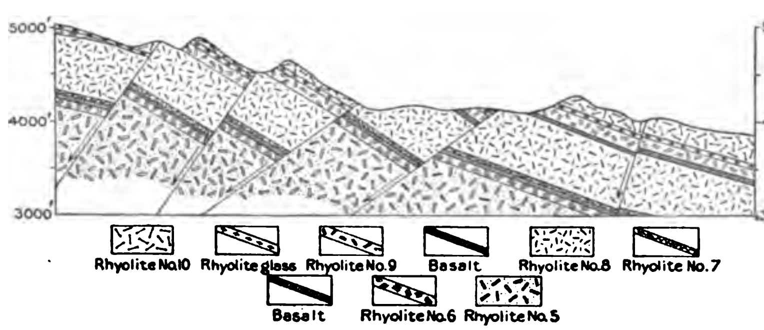


FIGURE 11.—Section northeast of Busch Peak, illustrating the erosion of fault blocks.

some of the blocks occurred far above its position in others. The maximum erosion since faulting began must have been at least 5,000 feet in order to expose the lower flows. Figure 11 is a section drawn through the summit of a hill (elevation 4,700 feet) 2,300 feet northeast of Busch Peak. It shows the result of erosion where the rocks are of unequal hardness. In this section rhyolite No. 10, which is very dense and resistant, forms the summits of the hills, while rhyolite No. 9, which is spongy and easily eroded, forms the saddles. Erosion must have accompanied faulting and the summits of the mountains may never have been very much higher than they are to-day. In general the present topography is the result of the dislocation of tilted

beds, combined with extensive and unequal erosion, rather than the direct expression of faulting.

DETAILED DESCRIPTIONS OF FAULTS.

ORIGINAL BULLFROG FAULT.

At the Original Bullfrog mine the rocks northwest of the vein are rhyolite flows No. 1 and No. 2. They strike N. 10° E. and dip about 25° E. (See Pls. I and IX, *A*.) South of the Original Bullfrog vein Silurian (?) limestones, with the associated quartzites and shale, strike approximately east and west and dip from 15° to 20° N. The relations of the rocks show that the vein occurs in a fault zone along which there has been great displacement. The outcrop, as shown on Plate I, is very sinuous, owing to the low north dip of the fault. The outcrop of the vein is at some places 200 feet wide. The vein material is white quartz, which cements a great number of brecciated fragments of rhyolite, shale, and limestone. The limestone under and south of the vein is also greatly crushed, and is traversed by many small veinlets trending in all directions. They are in the main much less than 1 inch wide and are composed of quartz and calcite. The Bullfrog Extension incline, which dips 18° N. and is located about 1,300 feet N. 70° E. of the Original Bullfrog mine, was, at the time of the visit, wholly in a thin layer of shaly material which lies above the limestone. The position of the rhyolite flows to the north, however, shows that the Original Bullfrog fault lies only a short distance north of the shaft. Eastward the fault passes under the wash, but the fact that limestone similar to that near the Original Bullfrog mine outcrops 1 mile S. 83° E. of that mine and is in contact by faulting with rhyolite No. 1 to the north indicates that the two exposures are on the same fault. The amount of displacement can not be determined at this point, but it is probably considerable.

AMARGOSA FAULT.

About 5,200 feet N. 86° E. of Velvet Peak the Tertiary lavas are faulted against the Silurian (?) limestone by the Amargosa fault. This contact extends south 3,300 feet to a point where the crystalline rocks are also faulted against the lavas. The latter contact here bends rather abruptly to the southwest and may be followed for about 2,600 feet to a point where it passes under the wash. The lava flows just north of the fault strike N. 30° W. and dip about 10° E., successively younger lavas being thereby brought in contact with pre-Tertiary rocks on the southeast. The dip of the fault is very low, as is shown by its outcrop (Pl. I), and the throw is probably greater than at the Original Bullfrog mine. The fault fissure on which is the Wildcat (or Bonanza) prospect, which lies to the east of the area

A. BULLFROG MOUNTAIN FROM THE SOUTH.

The low hills in the foreground are composed of limestone and shale, against which the volcanic flows forming the mass of the mountain are faulted. The Original Bullfrog vein outcrops along the face of the rounded hill in the left-middle distance.

B. MONTGOMERY-SHOSHONE FAULT.

The observer is looking northeast along the line of the fault, which passes through the saddle. The light rock on the left is rhyolite No. 16, above which are basalt No. 5 and quartz latite. On the right is rhyolite No. 10.

mapped, also has a low north dip and its throw is comparable to that of the Amargosa fault. The two faults may join under the wash of Amargosa River. Both the Original Bullfrog fault and the Amargosa fault have very low dips and both have Tertiary rhyolite on the hanging wall and pre-Silurian schists on the foot wall. The nearest outcrops of these two faults are more than 5 miles apart and the country between is covered by wash, but the line of contacts between the schist and the rhyolites suggests the presence of either a single continuous fault or else of a zone of profound faulting trending eastward along the southern margin of the Bullfrog Hills.[a]

BEATTY FAULT.

The low hill 1,500 feet northeast of Beatty and just east of the area mapped is composed of rhyolite No. 1, while rhyolite No. 11 outcrops just west and south of town. The rhyolites dip east at low angles and under the wash they must be separated by a fault, which has been named the Beatty fault. This has an apparent vertical displacement (see fig. 10) of about 5,000 feet and the west block is depressed with respect to the east block. The fault probably joins the Amargosa fault and perhaps has fully as great a throw as the latter. It is assumed that it dips toward the west and this direction of dip seems most consistent with the dip of the Amargosa fault near the junction. It is platted on the section with a steeper dip than that of the Amargosa fault, which is lower than the average dip of the faults.

BULLFROG MOUNTAIN FAULT.

The position of the flows north of Bullfrog Mountain with reference to those west of Sawtooth Mountain shows that between them, beneath the wash, is a fault with an apparent vertical displacement of about 2,400 feet. (See fig. 10.) This fault probably joins the Original Bullfrog fault. The dip is assumed to be 45°, which is approximately an average for the larger faults.

MONTGOMERY-SHOSHONE FAULT.

The fault zone that passes through the Montgomery-Shoshone mine is composed of two or more closely spaced and nearly parallel fissures which, collectively, will be called the Montgomery-Shoshone

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[a] Since the field work of Messrs. Emmons and Garrey was finished, the Ali Baba shaft in the town of Bullfrog has been sunk to a depth of 300 feet. The shaft went through 200 feet of alluvial material or wash and then into rhyolite. At the bottom the rhyolite is shattered and veined, the vein material being similar in general character to that of the Original Bullfrog vein. When visited in August, 1908, the 300-foot level, which had been driven 121 feet N. 66° E. from the shaft, was all in this vein material. Since then, according to a letter from Mr. A. J. Klamt, the superintendent, the drift passed into red shaly material and then into limestone. These conditions are similar to those at the Original Bullfrog mine and indicate that the Original Bullfrog fault continues east under the wash south of Bonanza Mountain. Mr. Klamt reports that the contact between the rhyolite and limestone dips 30° W. This is probably a local irregularity, and more extensive work would be likely to show a general dip of the fault contact to the north. It is not known, however, what are the relations between the Original Bullfrog and Montgomery-Shoshone faults south of Bonanza Mountain. (See Pl. I.)—F. L. R.

fault. At the shaft of this mine there is a well-defined fissure striking N. 65° E. and dipping 85° NW. Rhyolite No. 10 forms the southeast or foot wall and a down-faulted strip of basalt the northwest or hanging wall. The rhyolite, which on the surface forms the south or foot wall at the shaft, is a dense purplish-gray rock, almost free from dark fragments and in general appearance not unlike rhyolite No. 8, but west-southwestward this grades into a rhyolite containing many small, dark rhyolite and basalt fragments—the lower part of rhyolite No. 10. Still farther west the glassy basal facies of rhyolite No. 10 outcrops above rhyolite No. 9. The foot wall at the shaft, therefore, is the upper part of rhyolite No. 10. The underground relations of the fault zone are described on pages 106–108.

It is a current opinion among mining men that rhyolites Nos. 8, 9, and 10, which compose Montgomery Mountain, will be found on the south slope of Black Peak within 300 or 400 feet of the surface, but when the section is studied this appears very unlikely, for north of the fault zone rhyolite No. 16 outcrops at many places, and this, in the normal sequence, is separated from rhyolite No. 10 by flows of many hundred feet in total thickness, as is shown in the generalized section of figure 4.

In a trench about 400 feet northeast of the shaft 60 feet of basalt is exposed. At its north end the basalt is truncated by a fault dipping 50° NW. and the hanging wall is of crushed rhyolite. Its south end is similarly faulted, its contact with the rhyolite dipping about 60° NW. In the Providence mine, which is about 1,200 feet northeast of this trench, a finely slickensided surface, striking N. 42° E. and dipping 45° NW., is exposed. (See p. 111.) The hanging wall is rhyolite No. 16, with its characteristic glassy fragments, while basalt, much crushed and altered, forms the foot wall. Gray rhyolite (No. 10) lies immediately southeast of the basalt. Between rhyolites Nos. 16 and 10 the basalt for its entire width of 35 feet is sheared and crushed, as described on page 112.

The country to the northeast of the Providence mine is partly covered by débris from the hills to the west and the fault plane is not exposed, but there are a few outcrops of the foot-wall and hanging-wall rocks, so that the position of the fault is approximately known. Here rhyolite No. 16, or the quartz latite, where this has not been eroded, occurs on the northwest side and rhyolite No. 10 outcrops east of the fault. A few yards north of the Bullfrog-Shoshone shaft a block of basalt lies between rhyolite No. 16 on the west and rhyolite No. 10 on the east and is probably a remnant of the same basalt fault block that is visible in the Providence and Montgomery-Shoshone mines. Northeast of this outcrop the fault passes under the wash. West of the Montgomery-Shoshone shaft the fault appears in the Polaris workings and still farther west it passes under the wash.

Figure 12 shows that the flows on Bonanza Mountain are depressed with reference to those on Ladd Mountain about 1,600 feet, which is a figure of the same order as the apparent vertical displacement of the Montgomery-Shoshone fault, as shown on section A–A, Plate I. It is assumed that this fault passes between the two mountains and continues southwest toward the town of Bullfrog.

The 2,000-foot apparent vertical displacement of this fault, as shown on the vertical section represented by figure 10, is obtained by calculating the thickness of the flows displaced and is a fairly accurate estimate.

Two groups of metalliferous veins, one represented by those of the Montgomery-Shoshone mine and one by the veins on the south slope of Bonanza Mountain, are situated on opposite sides of this fault and, so far as known, are the only veins so situated. Both groups strike

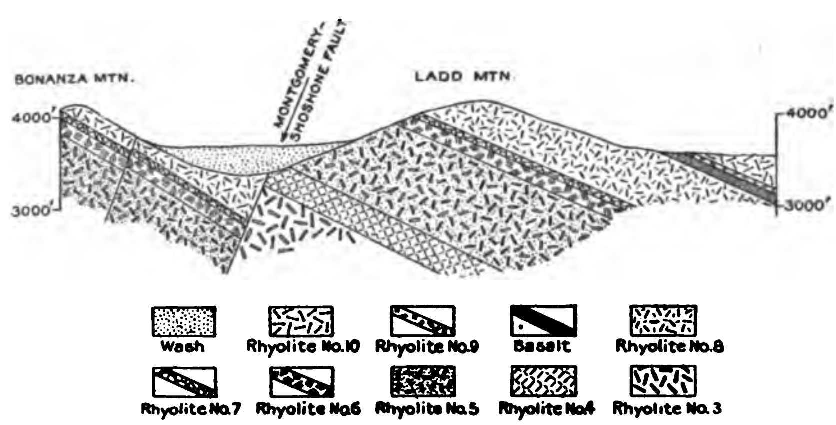


FIGURE 12.—Section through Bonanza and Ladd mountains, showing inferred position of the Montgomery-Shoshone fault.

approximately in the same general direction and have a somewhat similar mineralogical composition. The conjecture that they are a single vein group displaced by the Montgomery-Shoshone fault has been entertained, but no satisfactory evidence for its support has been found.

A mile N. 49° E. of the Montgomery-Shoshone shaft there is a group of prominent rock outcrops 800 feet long and 100 feet wide, which trends N. 30° E. The rocks stand from 20 to 30 feet above the nearly flat surface and have been incorrectly regarded by some as the silicified outcrop of rocks along the extension of the Montgomery-Shoshone fault. The rocks themselves are brecciated and in some places cut by veinlets of white quartz. Careful mapping at this place showed that the outcrop or reef is the faulted portion of a hard layer of rhyolite No. 11, which outcrops on the west spur of Burton Mountain and occurs at many places from 50 to 75 feet below the top of rhyolite No.

11. This layer, being harder than the more pumiceous rhyolite below and above, withstands erosion better and for the same reason is more easily fractured, but so far as is known it does not carry ore.

RUSH FAULT.

West of the summit of Sutherland Mountain the Rush fault does not show its dip, but its course is marked by a line of basalt débris. Rhyolite No. 5 outcrops on the east side of this line, while rhyolite No. 1 is exposed almost continuously along the west side. In the draw southeast of the hill (elevation 4,540+ feet) three-eighths mile north of Sutherland Mountain a small mass of rhyolite No. 7, with characteristic pink color, forms the east wall, which here is dropped down about 100 feet by a cross fault (the Saddle fault) that joins the Rush fault at this point. North of this point there is very little basalt along the outcrop of the Rush fault, though several small masses of it are exposed in prospect pits. This portion of the fault strikes a few degrees west of north and dips about 65° E. Its course here is gently sigmoidal as the fault descends the east slope of Box Canyon toward the north. The walls of this portion of the Rush fault are at many places crushed and there are slickensided surfaces parallel to the plane of the principal fault. The Rush fault is one of the few faults in the Bullfrog district that dip east. Its apparent vertical displacement where it is crossed by section A–A′, Plate I, is estimated to be 700 feet, and the displacement is considerably greater west of Sutherland Mountain. This shows that there has been unequal tilting of one of the fault blocks during settling.

SADDLE FAULT.

The Saddle fault passes over the saddle between Sutherland Mountain and Busch Peak and is conspicuous from Rhyolite (Pl. VIII, *A*). Where it joins the Rush fault rhyolite No. 5 forms its southwest and rhyolite No. 7 its northeast wall. In the saddle there is a remnant of basalt No. 2 on the southwest side of the fault and some of the same basalt occurs 100 feet lower on the northeast side. East of the saddle the slickensided faulted surface of rhyolite No. 6 dips about 70° NE. Farther southeast this fault appears to cross the Denver fault, though its intersection is not exposed. Both the Saddle and the Denver faults are mineralized near their intersection, and the distribution of the outcrops of the veins shows that neither fault is thrown very much out of line at the junction. Southeast of the crossing of the Denver fault is exposed a slickensided surface that strikes N. 16° W. and dips 63° NE. Toward the south this fault is concealed, but it is probably one of the two faults that inclose a horse of rock and, uniting beyond, pass through the Eclipse and Tramp shafts on the west slope of Bonanza Mountain. (See Pl. I.)

DENVER FAULT.

The Denver fault continues northward from the Denver mine and crosses the summit of the ridge joining Bonanza and Sutherland mountains, where its position is shown by a small patch of basalt, probably a faulted dike. The fault plane is concealed north of this point and since both walls are rhyolite No. 5 it can not be followed continuously. A mineralized fissure appears along the strike at an elevation of about 4,300 feet and a similar vein 2½ feet wide, standing slightly above the rhyolite, outcrops a few rods to the north of the intersection of the Denver fault with the Saddle fault. North of this point the Denver fault may be followed nearly to the top of Busch Peak, where it apparently splits, each portion joining a northeast-southwest fault a few rods north of the summit of Busch Peak. The vertical displacement of the Denver fault where it cuts basalt No. 2 on the south slope of Busch Peak is, as measured on a section at right angles to the strike of the fault, approximately 50 feet, and its nearly rectilinear outcrop over a diversified topography shows that this part of the fault plane is nearly vertical.

SCEPTER FAULT.

The Scepter fault, which apparently joins the east fork of the Saddle fault near the summit of the ridge north of the Eclipse shaft, outcrops also at an elevation of 4,200 feet on the northeast slope of this ridge. It is best exposed in the tunnel of the Voorhees-Murphy lease as a wide zone of shattered rock, striking north. Here its east wall is rhyolite No. 6 overlain by basalt No. 2 and rhyolite No. 7, and its west wall is rhyolite No. 5. At this point the dip is very steep to the east or else vertical. The fault probably passes a short distance west of the Great Eastern shaft, although it may be represented by a small fracture, with a dip of 75° E., which was encountered in that shaft. A short distance farther north the fault is more easily recognized and may be traced with only short interruptions across the basin, where brownish vitreous rhyolite (No. 5) forms its west or foot wall and porous white rhyolite (No. 6) its hanging wall. In a prospect pit a few rods southeast of the summit of the hill (elevation 4,180+ feet) three-fourths of a mile northwest of Rhyolite a slickensided surface is exposed, dipping 72° E. The hanging wall is basalt and the foot wall is rhyolite No. 5. The strike here is about N. 7° E. and the gouge streak along the fault slip is more than a foot wide. Farther north this fault brings rhyolites Nos. 6 and 7 on the west into contact with rhyolite No. 8 on the east. North of this point both walls are rhyolite No. 8, and since no basalt dike marks its course it is impossible to trace the fault farther. A slickensided surface, nearly vertical and with grooves and striæ perpendicular to the strike, occurs near the place where the projected line of the fault crosses a canyon west of

the spring that is about 600 feet northeast of the summit of Busch Peak. It is assumed that this striated surface is on the Scepter fault. The vertical displacement of the Scepter fault, as shown in a vertical section at right angles to the strike, is approximately 100 feet. The east wall was depressed. A west-dipping fault, which is probably coincident with the Lester vein for part of its course, joins the Scepter fault on the crest of the ridge north of the Lester shaft, which is on the west slope of Bonanza Mountain.

HOBO FAULT.

A fault striking N. 10° E. and dipping 55° W. joins the Hobo vein at the Hobo shaft. The vein is shattered at the fault and is marked by a slickensided surface, but exploration has not yet exposed the vein west of the fault and the throw of the fault can not be determined at this point. This fault, with approximately the same strike and dip, is also exposed on the surface in several prospect pits north of the Hobo shaft. (See Pl. XI, *B*.) Here a brecciated and slickensided basalt dike occupies the fissure. Rhyolite No. 6 forms the foot wall on the east side, while the hanging or west wall is rhyolite No. 8. North of these pits patches of basalt occur at intervals along the fault. The Hobo fault passes under the dump from the upper east-west crosscut tunnel of the Golden Scepter mine and still farther north it is covered by wash; but it is again exposed on the east slope of the hill (elevation 4,180+ feet) three-fourths of a mile northwest of Rhyolite, where there is a fault contact between basalt on the east and rhyolite No. 8 on the west. The fault plane here dips west and strikes approximately with the Hobo fault, as projected northward from its exposures on the east slope of Bonanza Mountain. Farther north the outcrop of this fault ascends the east spur of Busch Peak, bending sharply to the east as it rises, in consequence of its west dip. For the same cause it bends sharply west down the hill northward to the spring northeast of Busch Peak. Its presence is indicated by basalt débris nearly all the way. At the spring, where it is joined by a fault striking a few degrees east of north, the Hobo fault dips 35° W. and strikes about N. 25° E. It may be traced northeast of this point almost continuously for several hundred feet and it is exposed in a prospect (elevation 4,120 feet) on the northwest slope of the hill (elevation 4,260+ feet) 1,200 yards northeast of the summit of Busch Peak. At this point it dips about 35° W.

The vertical displacement of the Hobo fault, as measured on a plane at right angles to its strike on the Hobo claim, is less than 100 feet, and the west side or hanging wall has been depressed. The vertical displacement, measured in the same manner, east of Busch Peak near the spring above mentioned, is greater than this and where the section A–A′ crosses the fault the apparent vertical displacement

is estimated at 300 feet. This increased displacement toward the north may be explained by a differential throw, the north end of the western block being depressed more than the south end; or there may be one or more cross faults under the wash that unite with the Hobo fault from the east and allow the portion of the east block north of the intersection to move independently.

MECHANICS OF THE DEFORMATION.

GENERAL RESULT OF THE MOVEMENTS.

The attitude of the flows and tuffs in nearly every block of the fault mosaic is known through the presence of basal contact facies or of thin layers that contrast sharply with layers above or below them. The position and dip of the fault planes between the individual blocks are known from exceptionally good exposures on the surface and underground. The data are therefore full enough to warrant considerable confidence in the interpretation of details of structure as shown in the geologic map and in the various cross sections. Section A–A′, Plate I, is constructed through Black Peak and Burton Mountain. Figure 10 is an extension of section A–A′, drawn to include some beds exposed east of Beatty, outside of the mapped area. It is not quite perpendicular to the strike of the faults or flows, though at most places it crosses both, making large angles with their strikes. These angles have been taken into consideration in platting faults and beds on the section. They cause, in most cases, an apparent flattening of dip in the diagram and make the flows appear a little thicker than they are. The faults are represented as extending down with the dip observed at the surface. In the case of faults concealed by wash a probable dip was assumed. Figure 4 is a columnar section giving the estimated average thickness of the beds.

In figure 10 rhyolite No. 7 has been projected under later strata of known position and above older ones, its position being determined from the thickness of associated beds near by or from the average section as given on page 30. Most of the dips of flows as platted were observed near the plane of the section, but where the rocks are concealed by wash their dip was assumed. Figure 10 represents a length of 8 miles. Rhyolite No. 7 is represented in each fault block as extending to the next fault west, and if necessary is projected upward with the dip observed or assumed at the surface. The diagram may be objected to as unduly extending actual observation, but it so nearly represents the true relations of the beds as to be useful in clarifying discussion of the data, which for an intricately faulted and tilted region are unusually full.

In the fifteen fault blocks in which rhyolite No. 7 appears in this section the total downward depression due to tilting (the sum of the

vertical legs of the right triangles shown in fig. 10) is about 13,000 feet, the projection of the flow (the sum of the horizontal legs of the triangles) is 30,000 feet, and the extent of rhyolite No. 7 in the plane of the section (approximately the sum of the hypotenuses of the triangles) is 33,600 feet. The figure shows a slope to the east, due to tilting, that averages about 39 feet in 100 feet along the flows and corresponds to an average dip of about 23° E. in the plane of the section. This, however, does not represent the actual dip of the flows but only their apparent dip in the section of figure 10. Since the strikes of the flows are not exactly at right angles to the plane of the section, the actual dip is greater than the apparent dip. Sixteen field measurements of dip near the plane of the section average 27°, which may be taken as a very close approximation to the average actual dip of the flows.

The sum of the apparent horizontal displacements of all faults as shown on this section is 12,240 feet, which, added to the projection of rhyolite No. 7 on a horizontal line, equals the total length of the section, or 42,240 feet (8 miles).

There are nineteen faults in all represented in figure 10 and of these all but two dip west. According to the interpretation made, rhyolite No. 7 is displaced by fourteen of the faults, of which two have a downthrow to the west. Measurements of these blocks, as shown in the figure, give for the sum of the apparent vertical displacements of all faults, 13,750 feet; for the sum of the apparent vertical displacements of the faults which depress rhyolite No. 7 to the west, 12,500 feet; for the sum of the apparent vertical displacements of the two faults which depress rhyolite No. 7 to the east, 1,250 feet. Thus the apparent net depression of rhyolite No. 7 toward the west, resulting from all faults, is 11,250 feet. Tilting depresses this same rhyolite 13,000 feet to the east. The total apparent depression eastward, due to tilting and to downthrow to the east by faulting, is about 14,250 feet. Thus this flow as projected is only 1,870 feet lower at the east end of the section than at the west, and the tilting and faulting are nearly compensatory.

RELATIVE AGES OF TILTING AND FAULTING.

The tilting of the lavas occurred before or after they were faulted, or else the two processes went on together. Tilting before faulting is represented diagrammatically by figure 13, where an originally horizontal flow *ab* is tilted through 27° to *ad* and then faulted to *cd*. If it is assumed that tilting occurred before faulting, then rhyolite No. 7 (along the plane of section shown in fig. 10) after tilting should have been 13,000 feet lower at the east end of the 33,600-foot section of rhyolite No. 7 than the same bed was at the west end. If the period between the deformation by the two processes were long enough for any considerable erosion, evidence of such relief should

be preserved in this or adjacent districts in the form of a thick accumulation of derived sediments. These sedimentary rocks would now be faulted but not tilted. There is, of course, the possibility that nearly horizontal faulted sedimentary rocks of later age than the lavas do occur below the desert flats and that beds of the same age

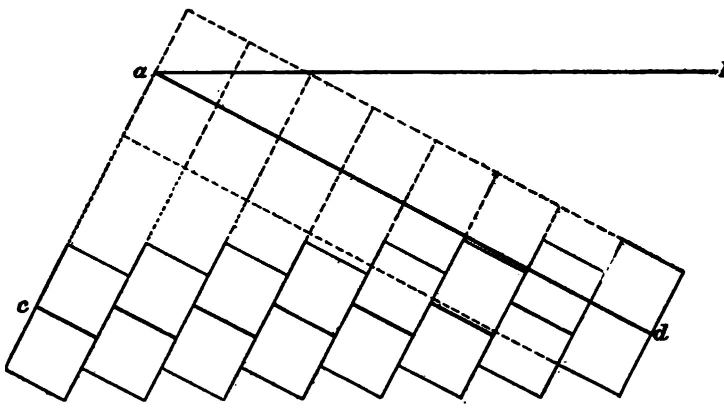


FIGURE 13.—Diagram illustrating tilting before faulting; vertical section at right angles to the strike of the faults. The originally horizontal flow *ab* is tilted to *ad* and then faulted to *cd*.

have been eroded from the higher country; but if all of the faulting had followed all of the tilting, with erosion and deposition between, the chances would have been good for the preservation of remnants of horizontal sedimentary beds, since faulting alone has caused displacement of more than a mile and without active simultaneous erosion must have produced that much relief. The absence of

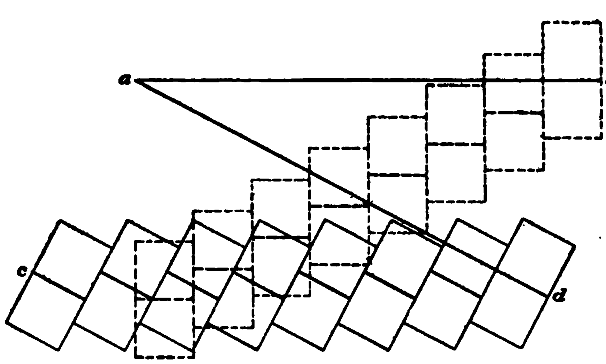


FIGURE 14.—Diagram illustrating faulting before tilting; vertical section at right angles to the strike of the faults. The originally horizontal flow is faulted with downthrow to the left and the series of blocks as a whole is then tilted to the position *cd*.

faulted but untilted rocks of later age than the lavas points toward the conclusion that the lavas were not tilted very long before they were faulted.

Faulting before tilting is represented diagrammatically in figure 14, where the bed *ab* is faulted with downthrow to the west, the segments

taking the position shown by the dotted lines. If the series is tilted 27° with *b* as an axis, these blocks take the position of the solid lines. If all of the tilting shown in figure 10 had occurred after all of the displacement by faulting, then there should have been a very great relief before tilting, for faulting, as expressed in this section, depressed the rocks 11,250 feet. If erosion had taken place between the operation of the two processes, unless it were vigorous enough to carry all of the detrital material entirely beyond the area examined, the débris should now form tilted sedimentary rocks, not faulted, and some remnants of such rocks would very probably remain at some place within or near the area. Although at many places the beds on different sides of a

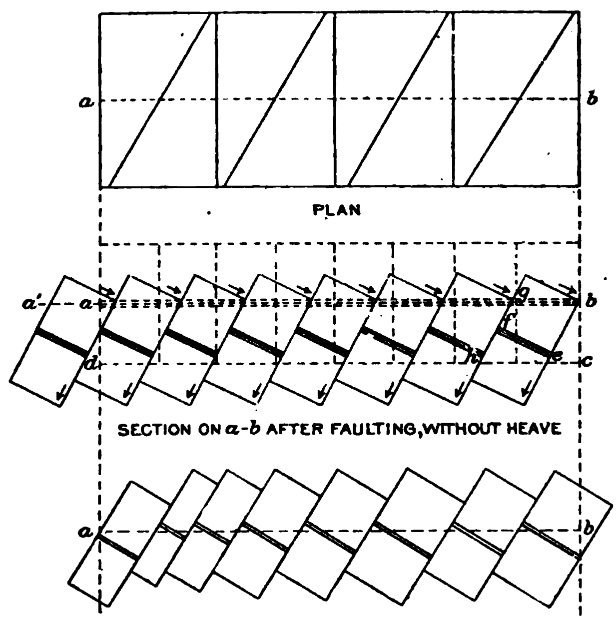


FIGURE 15.—Diagram illustrating simultaneous faulting and tilting. See text for explanation.

fault dip at different angles, there is very little variation of dip within single blocks. This fact further suggests the interdependence and contemporaneity of the faulting and tilting. The Silurian (?) limestone south of the Original Bullfrog fault does not conform in strike and is less steeply tilted than the lava flows to the north of the fault. If it is assumed that the hanging wall went down in this case, it follows that the east end of the block moved a greater distance than the west end in order to tilt the strata on the north side of the fault to the east. If all the tilting occurred before all the displacement along the fault the beds on the two sides of the fault plane would probably be inclined at about the same angle. The short geologic time which has elapsed since the beginning of the deformation of the lavas by

faulting and tilting suggests further that the two processes were nearly if not quite contemporaneous.

If faulting and tilting went on together, the effect would be that of rotation, each block moving more or less independently of adjoining blocks. Such movement is represented diagrammatically in figure 15, where the flow AB is cut by regularly spaced vertical fissures and the blocks are rotated independently without any tilting of the mass as a whole. As shown in this figure the horizontal distance through the blocks along the line A′–B is about 12 per cent greater after rotation than before, and in consequence the area of the horizontal section through A′–B is likewise increased 12 per cent, providing the width of the faulted area remains the same. If rotation occurred without extension along the line A′–B′ then there must have been a great horizontal movement or heave of the blocks along the fault planes while they were faulting. As shown in plan in the upper portion of this diagram, the faults cross one another, making angles of about 35°. This forms wedges, some of which present sharp edges to the plane of the section. If during deformation some of these wedges moved broad-part forward (at right angles to the line of the section) there would be room for the remaining blocks to settle without such great extension along the plane of the section. This horizontal element of movement along the faults of the Bullfrog district is recorded by inclined striæ on fault planes.

HORIZONTAL COMPONENT OF MOVEMENT ALONG FAULT PLANES.

The striations on the slickensided surfaces of the faults in the Bullfrog area make angles that vary from a fraction of a degree to 90° and have an average pitch of about 60°. Consequently the movement must have had a considerable horizontal component. Observations of recent faulting in California show that horizontal movement may be very important and that in some cases there seems to have been very little vertical movement. Figure 16 shows beds that have been tilted and that are cut by a fissure of which the dip is opposed to that of the beds. The strike of the fissure makes an acute angle with the strike of the beds. The left half of the block is shown to move horizontally toward the reader. This results in an apparent normal displacement that, when seen only in cross section, appears to have been straight up or down the plane of the fault. This effect is not produced when the beds are flat or when the strike of the fault is parallel to the strike of the beds, provided the movement is entirely horizontal; but the vertical displacement and horizontal displacement increase as the angle between the strike of the fault and the strike of the beds increases and are greatest when this angle is 90°. As shown in figure 16, there is, after faulting, an overlap of strata in the plan and a gap in cross section. If the left half, on

the other hand, had moved in a horizontal direction away from the reader (see fig. 17), the result would be an apparent reverse fault, or one in which the foot wall appears to have dropped with respect to the hanging wall. There is a gap in plan and an overlap in vertical section. With sufficient horizontal movement in the proper direction, such an apparent reverse fault might result even when some of the movement of the hanging wall was down the dip of the fault plane.

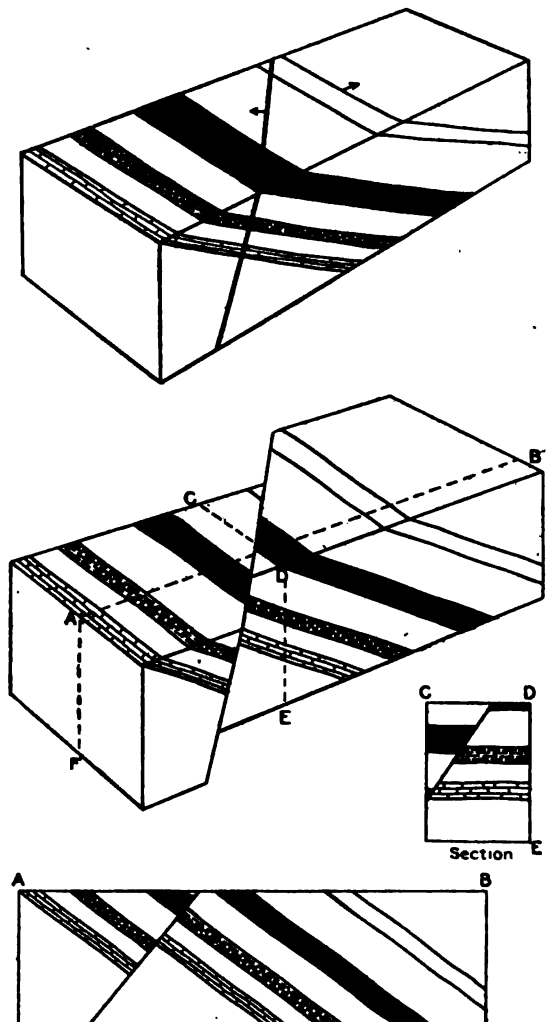


FIGURE 16.—Diagram illustrating some of the effects of heave along a fault in tilted beds. See text for explanation.

A study of the Bullfrog map shows that most of the offsets of strata due to faulting are such as could be produced by movement of the hanging-wall side down the dip, without horizontal displacement or heave. But nearly everywhere there is an offset with an overlap instead of a gap. This shows that the horizontal element of movement of the blocks, however great it may have been, was in the direction which increased the apparent vertical displacement, or else its offsetting effect on the tilted beds was less than that caused by vertical movement, for if it had been greater and in an opposite direction a gap would have resulted where the relations of beds to fault planes are like those shown in figure 17, and the fault, as shown in vertical sections, would have been reverse. Since in the Bullfrog district no clearly reverse faults are shown and since there are no gaps on the surface such as would indicate

them, it seems very probable that forces causing horizontal movement always operated in one direction, and so as to increase the

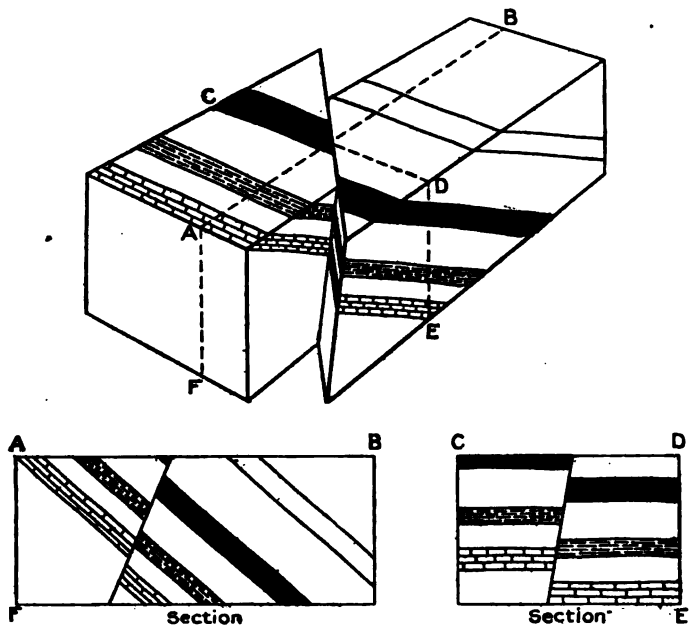


FIGURE 17.—Diagram illustrating some of the effects of heave along a fault in tilted beds.

apparent displacement. As already stated the directions of striæ observed, taken all together, show that, in the movement recorded, the vertical component was greater than the horizontal component.

DEFORMATION AND CHANGES IN AREA.

It is generally recognized that crustal shortening accompanies folding of strata. If a horizontal bed is tilted, without faulting, either it must be stretched or the rocks below must move or be compressed to meet the new conditions. The jointing of the rocks in the Bullfrog district shows that there has been some stretching, though certainly it is insufficient to meet the demands required by any considerable crustal shortening. On the other hand, tensional stress is commonly regarded as a condition for normal faulting and this appears to be necessary if the blocks move downward freely without crumpling the strata.

If the various sections of rhyolite No. 7, as represented in figure 10, were horizontal and placed end to end, the resulting section would be 33,600 feet long. The horizontal distance over which the small sections are now distributed is 42,240 feet. The difference is 8,640 feet, or 25.6 per cent of 33,600 feet, which, for this whole section, represents the apparent net crustal extension due to faulting and tilting. Sections making large angles with that of figure 10 also indicate an apparent extension, as is shown by section D–D′ of Plate I.

That horizontal displacement with gap, as shown in vertical section, does not always represent real extension of the earth's surface is apparent from inspection of figure 16, where both cross sections A-B and C-D show gaps, while the plan ABCD shows an overlap. The movement represented has been along the strike of the fault, and while the area itself has been unchanged the disposition of the surfaces of the individual blocks is different. Yet as seen in vertical cross sections A-B and C-D the faulting has resulted in horizontal displacement with gap. However, this extension is only apparent, for, as seen in plan, it is compensated by the offset with overlap. All three dimensions, length, breadth, and thickness, should be considered in the discussion of the problem. As there has been no appreciable change of density in the material of the rocks in consequence of deformation, it is evident that the thickness of a faulted block must decrease if the length or breadth increases. Part of the overlap shown in the map of the Bullfrog area may be regarded as the expression of the shortening in this vertical direction, as shown diagrammatically in figure 16. From an inspection of the diagrams above referred to, it appears that the whole truth is not to be gained by measurements of distances between points of separation of beds in a few cross sections. The operation serves to indicate the kind of effects produced, but it is not accurately quantitative. It shows only that extension has taken place along the line of section; it does not show how much of this is due to horizontal movements (heave) in the directions of strike of the faults. As already stated, the horizontal component of the movement is less, on the average, than the vertical component in those faults where the direction of movement is recorded by striæ. It is estimated that about one-third of the apparent crustal extension shown in figure 10 is due to horizontal displacement of blocks along the strike of fault planes by movement that does not effect a change of area, but only a change in position of certain blocks. In accordance with this estimate the extension of the surface approximately at right angles to the strike of the faults would be two-thirds of the 25.6 per cent extension calculated from that shown in figure 10, or about 16 per cent. Further, if the individual blocks retain their shapes and dimensions, it is evident that the combination of tilting and inclined faulting does not extend the area in a direction parallel to the strike of the faults, but only in a direction at right angles to this. If all the faults were strictly parallel, the areal extension would be the same as the linear extension in a direction at right angles to the faults. No correction for heave would be necessary and the general section of figure 10 would show directly an extension of about 16 per cent. In other words, an area of 1 square mile would be, after faulting and tilting, 1.16 square miles.

SUMMARY.

A study of the faults in the Bullfrog area leads to the following conclusions:

1. All the faults are normal, since the hanging walls appear to have been depressed with reference to the foot walls.

2. Tilting and faulting, in the main, followed the extrusion of all the lava flows now present.

3. As there is no record of sedimentation in the interval between faulting and tilting, the two processes probably operated at the same time, and if so the movement was to some extent a rotation of the blocks in a measure independent of one another, so that fault planes were tilted as well as strata.

4. The lateral or horizontal element of the movement (heave) along fault planes was considerable, though it was less than the vertical element.

5. The horizontal displacement with gap, which appears in all cross sections of faults and beds, does not indicate the actual extension of the surface. The apparent extension of 25.6 per cent, as shown in figure 10, is estimated to represent an actual extension of not more than 16 per cent.

PART II.—ECONOMIC GEOLOGY.

By F. L. Ransome.

THE MINES; A GENERAL ACCOUNT OF THEIR DISTRIBUTION AND DEVELOPMENT.

By far the most important mine in the Bullfrog district is the Montgomery-Shoshone (Pl. X, *B*), situated 1½ miles northeast of Rhyolite, in the pass between Montgomery Mountain and Black Peak. The workings lie on the southeast side of the Montgomery-Shoshone fault and are mainly in rhyolite No. 10. The main shaft is 600 feet deep and is connected with about 9,000 feet of drifting. The ore as delivered to the company's mill at the mine in July, 1908, averaged from $10 to $15 a ton in assay value. The ratio of gold to silver in ounces is approximately as 1 to 17, but is not uniform. About 150 tons of ore are milled in twenty-four hours and the gross monthly output is from $50,000 to $70,000. Northeast of the Montgomery-Shoshone mine, on the same fault zone, are the Providence, Lucky Jack, and Red Oak mines, none of which has been productive. The Steinway shaft, about 2,300 feet west of the Montgomery-Shoshone, and the Yankee Girl shaft, in the flat just northeast of Rhyolite, are prospects which when visited in 1906 were about 200 feet deep. They were not being worked in 1908. The Amethyst, a prospect on a minor fissure north of the Montgomery-Shoshone mine and fault, was also idle at the time of last visit.

On Ladd Mountain (Pl. XI, *A*), east of Rhyolite, the principal workings are those of the National Bank mine in rhyolite No. 5. This shaft was 200 feet deep in 1906, with two levels. Although some ore has been found, the mine has not been profitable and was closed in 1908. The tunnel of the Bullfrog Mining Company has been driven into the west base of Ladd Mountain for over 550 feet, but has not opened workable ore bodies. At three or four places on the west slope of the hill lessees have discovered bunches of ore near the surface, in rhyolite No. 5, and shipments were being made from two such sets of shallow workings in 1908.

Due west of Rhyolite is Bonanza Mountain, in which are the workings of the Tramps Consolidated Mining Company, including

A. OPEN STOPE OR "GLORY HOLE" OF THE MONTGOMERY-SHOSHONE MINE.

Photograph by A. E. Holt.

B. MONTGOMERY-SHOSHONE MINE AND MONTGOMERY MOUNTAIN, FROM THE NORTH.

Photograph by A. E. Holt.

the Denver mine, and of the Gibraltar mine. The Denver, which has shipped considerable ore, is on a nearly north-south vein in rhyolite No. 5. The workings consist of four tunnels, mainly on the vein, with a winze about 300 feet deep below the No. 4 tunnel. There are levels at approximately 50, 150, 250, and 300 feet below the collar of the winze. The total length of the vein explored is about 700 feet and the total depth is about 500 feet. The Denver mine has no mill and the ore is hand sorted and shipped.

Southeast of the Denver mine are the Tramp, Eclipse, and Hobo workings of the same company. These are mainly in rhyolite No. 5 and consist of several tunnels and shallow shafts, which explore a block of ground about 1,700 feet long from north to south and about 900 feet wide. The principal tunnels or adits are the Tiger, which runs northeast and enters the vein zone at the north end of the explored area, and the Tramp, which runs northwest under the summit of Bonanza Mountain. The two tunnels are connected by a raise of 106 feet from the Tramp tunnel to a drift from the Tiger tunnel. The maximum vertical range of exploration is about 400 feet. Within this block are from eight to ten recognized veins, some of which accompany basaltic dikes. Their general trend is nearly north and south. Although considerable low-grade oxidized ore and some small bunches of rich ore have been discovered, the workings have not been productive.

On the southeast side of Bonanza Mountain are the workings of the Gibraltar mine on a series of nearly north-south veins, of which the productive parts are mainly in rhyolite No. 6. There are two tunnels that follow one of these veins and one crosscut tunnel. The mine has been irregularly worked on a small scale by lessees, who have sorted the ore by hand and shipped it out of the district. A shaft 300 feet deep was sunk by the Gibraltar Company through the alluvium south of Bonanza Mountain, but no ore was found and these workings were abandoned.

North of the summit of Bonanza Mountain the Scepter fault (see Pl. I) has been prospected unsuccessfully through the Golden Scepter shaft and tunnel and through the Great Eastern shaft. These shafts were closed at both times of visit.

At the south base of Bullfrog Mountain, 3 miles west of Rhyolite, are the Original Bullfrog and Bullfrog West Extension mines. These are on a large vein, in places fully 60 feet thick, which dips north at angles rarely exceeding 18°. The vein is a mass of much-shattered rhyolite that forms the hanging wall of the Original Bullfrog fault fissure (see Pl. I) and that has had its fractures and interstices filled with quartz and calcite. The vein material is of low grade as a whole, but the Original Bullfrog mine has shipped a little rich ore, which was found in bunches in the vein. The Bullfrog West Extension

mine is 195 feet deep, with three levels, the lowest being entirely in limestone and shale in the foot wall of the vein. There have been no shipments of importance and the future of the mine depends upon the possibility of milling low-grade ore in quantity. The Big Bullfrog is a prospect in the schists south of the Original Bullfrog mine. No ore was found and the shaft had been abandoned in 1908.

About 4 miles northwest of Rhyolite and outside of the mapped area are the Gold Bar and Homestake-King mines. These are on a north-south zone of fissuring and mineralization in rhyolite. The Homestake-King, 500 feet deep, was the only one of these in operation in 1908. It has a modern 25-stamp mill, which at the time of visit had just begun running. The ore of both mines is generally of low grade.

About 7 miles north of Rhyolite is the Mayflower mine, 200 feet deep. The vein is a broad, low-grade zone of fissuring and mineralization in rhyolite. No work was in progress during the summer of 1908 and the mine has never been productive.

The Keane-Wonder mine, sometimes referred to as being in the Bullfrog district, lies on the Death Valley side of the Funeral Range, about 15 miles south-southwest from Rhyolite, which is its supply and shipping point. It is on a flat vein in rocks supposed to be of Cambrian age.[a] The mine was producing actively in 1908, but was not visited and lies entirely outside of the area with which this report is concerned.

From this summary it appears that the Bullfrog district contains only one mine of moderate size and of steady productiveness. The others are all small and up to the middle of 1908 no one of them could be said to have emerged from the prospecting and experimental stage. Whatever the expectations excited from time to time by the finding of superficial bunches of rich ore, there can be no doubt that the veins as a whole are to be classed as low grade when the conditions under which they must be exploited are taken into consideration. They are in no way comparable with the remarkable bonanzas that have brought fame to Goldfield and can not be successfully worked by the same methods.

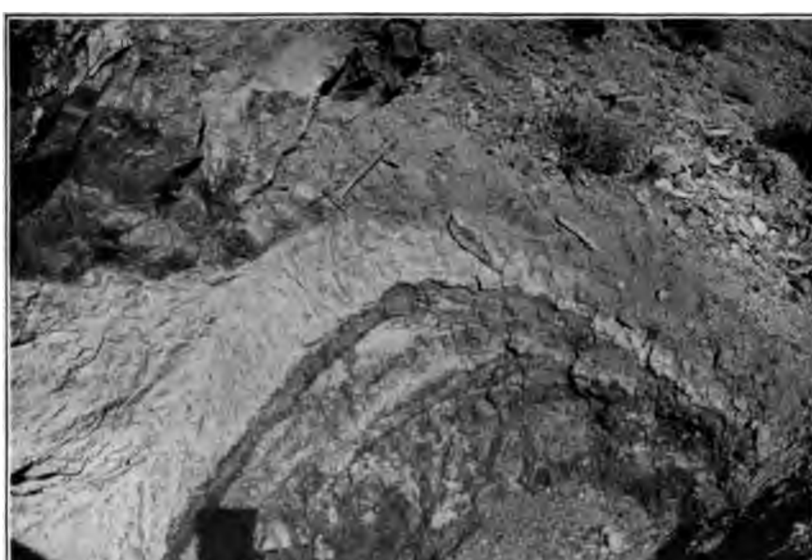
MINERALOGY OF THE ORES.

Introductory statement.—All of the ore thus far mined in the Bullfrog district is oxidized and consequently the deposits lack much of the mineralogical interest of those at Goldfield, where may be studied not only the products of oxidation but the original sulphides whence these have been derived. Moreover, the ores of the southern district, so far as can be judged from present exposures, do not in their original

[a] See Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, p. 174.

A. LADD MOUNTAIN AND THE TOWN OF RHYOLITE, FROM THE NORTHWEST.

Beyond Ladd Mountain, to the left, is Bare Mountain. To the right is the Amargosa Desert.



B. PIT ON HOBO VEIN AND FAULT FISSURE.

Shows superficial overturning of the soft, crushed material by downhill creep.

condition present the variety and complexity that render Goldfield so much more attractive a field for the mineralogist.

Gold.—The native gold of the Bullfrog district where visible in the ores has the form of small specks, which, as a rule, are in the center of a spot of limonite. Evidently the gold was once in pyrite, the oxidation of which has produced the limonite. Large crystalline or showy masses of gold are unknown. The native metal is generally pale and contains a considerable proportion of silver. In the Original Bullfrog mine the gold is in part embedded in chrysocolla, and from this source have come the only specimens from the district that have any pretension to mineralogical distinction.

In some ore from the Hobo shaft on Bonanza Mountain the gold is in nests of little hackly particles, associated with minute quantities of a dark metallic mineral, which may possibly be a telluride. Not enough of this could be obtained, however, for chemical tests.

Galena.—Galena is not known in any of the mines, but is present in small quantity in some quartz veins in the pre-Tertiary metamorphic rocks south of Beatty.

Chalcocite.—Chalcocite, cuprous sulphide, is sparingly present in some of the ore of the Original Bullfrog mine as small irregular particles peripherally altered to chrysocolla.

Pyrite.—Pyrite is not abundant in the ores now mined owing to its general alteration to limonite. Small crystals may be seen occasionally in some of the ore of the Denver mine, and the mineral makes up a small part of the concentrates of the Montgomery-Shoshone mill. None of the veins appear to have been originally rich in sulphides, and it is doubtful whether below the zone of oxidation pyrite will constitute more than a very small part of any deposit.

Cerargyrite.—Cerargyrite, or horn silver, is probably present in many of the veins but is not a conspicuous mineral. Even in the Bonanza ore of the Montgomery-Shoshone mine above the 200-foot level, much of which averaged over 600 ounces of silver to the ton, cerargyrite does not appear to have been a very noticeable constituent. The mineral has been detected by panning in a streak of oxidized ore near the mouth of the Tiger tunnel of the Tramps group, on Bonanza Mountain, and could probably be found elsewhere in the district by similar search.

Quartz.—The prevalent form of the primary quartz of the veins is that of irregular or xenomorphic aggregation with calcite. Much of it is cryptocrystalline and this variety has in part formed by silicification of fragments of rhyolite. Coarsely crystalline transparent quartz or quartz with well-developed crystal faces is not characteristic of the veins of Montgomery, Ladd, or Bonanza mountains.

Nearly all of the oxidized ore contains some secondary quartz,

partly as the skeletal pseudomorphs after calcite described below and partly as thin crusts and druses lining cavities.

The quartz of the Original Bullfrog and Bullfrog West Extension mines and of the Ali Baba shaft south of Bonanza Mountain is of a different character from that of most veins in the district. It is coarsely crystalline and much of it is delicately amethystine. At the Original Bullfrog mine a large part of the vein material is beautifully banded, yellowish chalcedonic layers alternating with crusts of radially crystallized transparent quartz up to 4 or 5 inches in thickness. (See Pl. XII, *A*.) There is no constancy in the direction of this banding. It appears in most places to represent crustification around fragments of rhyolite and of shattered calcitic vein material previously deposited. The quartz also belongs to two or more periods of formation separated by movements which shattered the vein and produced open spaces to be filled by fresh deposition of quartz.

Limonite.—The common hydrous oxide of iron is a constituent of all of the oxidized ores and gives them their rusty appearance. It has been formed by the weathering of pyrite and presents no features of special interest.

Wad.—Under the name of wad are included various earthy, impure, hydrous oxides of manganese, which are not crystalline and which probably do not have a definite chemical composition. Such dark, manganiferous material is very common in the oxidized veins of Bonanza and Montgomery mountains and is the principal residual product from the solution and removal of the calcite from the veins. (See Calcite.)

Calcite.—Calcite is a common gangue mineral in most of the veins, usually crystallized with quartz in rather fine grained, dull white aggregates. In many veins or parts of veins, however, the calcite is coarsely crystalline and forms bands or bunches in the finer-textured vein filling. It has not been found in large, well-formed crystals. Calcite is abundant in the veins of Bonanza and Montgomery mountains.

Under the action of oxidizing solutions the calcite in the veins succumbs before the quartz and is carried away, leaving behind an earthy residue, which consists largely of hydrous oxides of manganese and iron. Thus a cavernous structure and the presence of sooty, impure manganese oxide are very characteristic of the weathered portions of the calcitic veins. All steps of this process may be studied in the field, and specimens showing the uneven corrosion of masses of clear calcite and the deposition of the oxides are readily obtainable. The attack upon the anhedral crystals is not wholly peripheral, but takes advantage of cleaving planes and minute irregular cracks. By the study of cleavage blocks of the more coarsely crystalline forms of the calcite it may be seen that the first step in the process is a clouding

of the mineral due to the separation of minute particles of manganese and iron oxides from the originally clear or milky spar. At a more advanced stage of the alteration the crystal is opaque and as seen under a lens is minutely porous. This dark, spongy material, which still contains calcite, grades in turn into a nearly black earthy mixture of oxides, from which all the calcium carbonate has been removed. A cleavage block of calcite from the Gibraltar mine on Bonanza Mountain was analyzed in the Survey laboratory by Dr. Chase Palmer with the following result:

Chemical analysis of calcite from the Gibraltar mine.

SiO_2	8.59
Al_2O_3, Fe_2O_3	.10
FeO	.13
CaO	50.50
CO_2	39.33
MnO	.93
	99.58

Approximately 10 per cent of the mineral was insoluble in hydrochloric acid and a considerable part of the manganese oxide was in this residue, although the material analyzed showed no perceptible alteration and it was supposed that whatever manganese was present would be in the form of carbonate. The quantity of silica found was greater than the appearance of the sample would suggest.

The weathering of the calcite is in many places accompanied by some silicification. The silica penetrates the calcite along cleavage cracks and when the calcium carbonate has all been removed the secondary quartz remains as fragile septa. Some of these are in parallel groups, others intersect at the angles of the rhombohedral cleavage, and still others at various angles dependent on the original juxtaposition of differently oriented calcite anhedrons. Between the septa are angular spaces whose walls are lined with minute quartz crystals and which are as a rule partly filled with impure wad. Such fragile, cellular, manganiferous material is highly characteristic of the oxidized portions of the veins in this district. The earthy oxides are in a few places lacking and the delicate pseudomorphous siliceous combs are there of snowy whiteness.

Parts of the oxidized zone in some veins show a late deposition of clear calcite as crusts on oxidized or partly oxidized material, as may be observed in the Tramp tunnel in Bonanza Mountain and in the Ali Baba shaft in the town of Bullfrog.

Malachite.—The green hydrous carbonate of copper has been found in small quantity at the Original Bullfrog mine associated with chrysocolla and gold.

Chrysocolla.—Chrysocolla, a hydrous silicate of copper, is moder-ely abundant at the Original Bullfrog and Bullfrog West Extension ines, where it forms bunches, streaks, and films in quartz. In most ' the rich ore obtained from the Original Bullfrog mine native gold ay be seen embedded in greenish-blue chrysocolla. It is the color ' this ore that is reported to have suggested the name of the district. he chrysocolla appears to have been derived from chalcocite, which turn may have formed from chalcopyrite.

STRUCTURAL FEATURES OF THE DEPOSITS.

In general the deposits of the Bullfrog district are fissure veins in rhyolite. The minor structures of those portions of the veins at present visible are more or less obscured by oxidation, but the fracturing that was followed by ore deposition appears largely to have taken the form of sheeting or brecciation of the brittle rhyolites, and to a less extent has resulted in simple open fissures. Consequently the larger veins contain numerous fragments of rhyolite, and the boundary between the vein proper and adjacent rhyolite, which in most places contains small irregular stringers of quartz, or quartz and calcite, is not in every case distinct.

Out of the twelve to fifteen veins that have been explored by other than by mere surface pits all but two strike nearly north and south and dip at angles greater than 50°. The exceptions are the Original Bullfrog vein, which strikes nearly east and west and dips north at angles generally less than 20°, and the contact vein in the Montgomery-Shoshone mine, which strikes and dips with the Montgomery-Shoshone fault zone. (See Pl. XIV.) The Mayflower vein, north of the area specially studied, strikes northwest and dips about 65° SW. Some of the approximately north-south veins, among which may be mentioned the Montgomery-Shoshone, Denver, and Eclipse lodes, while showing variation on different levels, are on the whole nearly vertical; others, like the Polaris, National Bank, Gibraltar, Hobo, and Lester veins dip west. Decided and persistent dip to the east is rare. The Eclipse, although very steep, might be classed as an eastward-dipping lode and the upper part of the Denver vein dips in the same direction.

Veins and faults are in this district very closely associated. The veins, like many of the basalt dikes, occupy for the most part fissures that were formed at the time the region received its present elaborate structural dissection. Out of the 100 or more faults of sufficient importance to be shown on a map of the scale of Plate I, certainly not over 15 per cent and probably not over 10 per cent are associated with veins of known or prospective value. Most of the fault fissures show no deposition of vein material whatever and the most promising veins occupy fissures that as elements of geologic structure have only

slight importance. The Denver vein and the veins of Bonanza Mountain generally have been deposited in fissures along which the displacement probably does not exceed 100 feet and in most places is much less. As dislocations these are insignificant in comparison with the Rush fault west of Sutherland Mountain or with the Bullfrog Mountain and other faults that, although themselves concealed by alluvium, are evident enough in the structure of the district. The nearly north-south veins of the Montgomery-Shoshone mine appear to occupy fracture zones of very slight displacement, which converge southward into a fissure that corresponds to a minor fault crossing one of the tectonic blocks into which the region is dissected.

The great Montgomery-Shoshone fault, which Messrs. Emmons and Garrey estimate to have a throw of 2,000 feet, limits the ore of the mine on the north, as is described on page 109. The manner in which the north-south veins end at this fault zone, which is in part occupied by a strip of basalt No. 4, is shown in Plate I. The contact vein, which follows the southeast side of the zone, has already been referred to as exceptional, since it differs in trend from most of the veins and is associated with one of the great dislocations. It can scarcely, however, be said to constitute a mineralization of the fault zone itself. It is rather a mineralization of the fissured rhyolite of the foot wall and its ore bodies are in many places clearly related to the ending of north-south fissures at the fault zone. As explained on page 106, the main movement along the Montgomery-Shoshone fault appears to have been on the northwest side of the zone and to correspond to fissures not reached by the Montgomery-Shoshone workings. There is no evidence as yet that any important mineralization has taken place along these fissures.

Another exceptional vein is the Original Bullfrog, which is very closely associated with the fault of the same name. This remarkable dislocation, which (see p. 122 and Pl. I) if not identical is probably connected with the Amargosa fault to the east, is apparently of the normal type, since younger rocks in the hanging wall are brought against older rocks in the foot wall. The dip, however, is so low (20° or less) as to make necessary the supposition that movement along this fault was effected by some strong lateral thrust. As the rhyolitic flows were forced over the uneven foot wall of the pre-Tertiary rocks, they were extensively fractured, and this fractured rhyolite, cemented and in small part replaced by quartz and calcite, constitutes the vein.

Many of the fault fissures, as shown in Plate I, are occupied in part by basaltic dikes. These are older than the veining, as may be well seen in the Tramps mine, where the Hobo vein at one place cuts obliquely across its accompanying dike. At other places veinlets

and stringers of the same character as the larger veins have been noted in the dikes. So far as is known, however, no ore occurs in this rock.

Since the veins were formed movement along some of the fissures has continued. This is particularly true of the Hobo (Pl. XI, *B*), Eclipse, and Gold Bar veins. Such movement is recorded by seams of gouge, accompanied by slickensiding and striation, which in some places intervene between the vein and its walls and in other places are wholly within the vein. The low-angle faults of small throw that displace the Eclipse and Hobo veins (see p. 117 and fig. 19) and the Denver vein (see p. 121) belong to this class of movements subsequent to vein formation. These late slips apparently record relatively slight displacement.

The lode fissures, in brief, were formed at the time the region received its present faulted structure and were for the most part accessory or subordinate effects of the stresses to which that structure is due. Faulting was succeeded by intrusions of basalt that in many places ascended the fault fissures as narrow dikes. After the basaltic intrusions there was renewed movement along some of the fissures, with perhaps some fresh dislocation, followed by vein deposition.

The veins show various gradations between fairly regular sheeted zones in which parallel banded veinlets composed of alternating crusts of quartz and calcite are separated by thin slabs of rhyolite, through irregular stringer lodes, to veins made up in large part of angular fragments of rhyolite cemented together by quartz or calcite or both. As a rule there is very little replacement of the walls or of the larger rock fragments by vein minerals. Between the smaller fragments, however, and the fine-grained white quartz of the fissures there is in many places no definite boundary. Much of the finely crushed rhyolite that presumably once partly filled the interstices between the larger fragments has been transformed to cryptocrystalline quartz. Banded structure is well shown in some of the cuts on the Hobo vein on Bonanza Mountain, where oxidation has gone just far enough to accentuate the structure by partial decomposition of some of the calcite layers to black manganese oxide. The crusts range from less than a sixteenth to half an inch in thickness. Close inspection shows that they are not altogether due to alternate deposition of calcite and quartz on the walls of a fissure. The constituent crystals of some of the quartz layers point inward from both sides, giving typical comb and vug structure along the medial plane of the layer and showing that the quartz was deposited as a little veinlet along a crack in older calcite. In some parts of the lode also the banded portions have crystallized in fissures that cut an older and less regular deposit of calcite and quartz. It thus appears that the

A. BANDED QUARTZ OF THE ORIGINAL BULLFROG VEIN.

B. SHATTERED AND VEINED RHYOLITE, ORIGINAL BULLFROG MINE.

veins were probably filled in three or more stages and that the quartz is in part younger than the calcite.

Where oxidation is well advanced, as is the case in most of the underground workings, the original structure of the veins is obliterated, and those in which calcite was abundant become soft structureless masses in which stained fragments of rhyolite and quartz are confusedly mingled with earthy ferruginous and manganiferous material or are embedded in the friable pseudomorphous masses described on page 94.

The Original Bullfrog vein differs from the other veins in the district as much in structure as in mineralogy. It consists mainly of quartz with subordinate calcite. Part of the quartz is cryptocrystalline and represents silicified fragments of rhyolite. The greater part, however, is very conspicuously banded, as may be seen from Plate XII. Curved layers of clear vitreous quartz (Pl. XII, *A*), much of it amethystine, run in various directions and alternate with striped chalcedonic crusts. The structure is complex in detail. Some of the calcite is older than the quartz, and the chalcedonic layers are cut by many veinlets of pure vitreous quartz up to 6 inches in width. Finally the whole brittle mass has been fractured and, in places, shattered by movement subsequent to the last period of deposition. On the hanging-wall side the vein grades into much-altered shattered rhyolite, traversed by innumerable branching veinlets of quartz, as may be seen in Plate XII, *B*.

The vein was originally a mass of shattered rhyolite that appears to have been first cemented by the deposition of quartz and calcite. This was again fissured and quartz was deposited abundantly in the open spaces and to a large extent replaced the fragments of rhyolite and the earlier-deposited calcite.

ACTION OF VEIN-FORMING SOLUTIONS ON THE WALL ROCKS.

The depth of oxidation and the shallowness of most of the mines make it impossible at this time to carry out any thorough study of metasomatic processes in connection with the deposition of the veins. It is safe to say, however, that the solutions which rose through or filled the fissures have left scarcely any trace of their chemical activity outside of the actual channels through which they moved. The rocks of the district as a whole are fairly fresh and show only the effects of normal weathering. Pyritization, sericitization, alunitization, or other kinds of alteration such as in most regions traversed by ore-bearing veins have affected the rocks over considerable areas are noticeably absent and the sole secondary change discernible in most of the rhyolites is the devitrification of the originally glassy groundmass into the usual fine-grained aggregate in which quartz

is the only mineral identifiable under the microscope. This change takes place so readily in siliceous glassy rocks that it is difficult in some cases to distinguish sharply between such devitrification and original crystallization from the molten state. It has no necessary connection with ore deposition.

To some extent small particles of rhyolite lying in the fissures have been replaced by fine-grained aggregates of vein quartz or of quartz and calcite. In a few places also the walls of fissures have been slightly modified by the same process, as is shown by the irregular character of the contact between vein and wall rock, seen in thin section under the microscope. On the other hand, the feldspar phenocrysts in specimens of rhyolite taken from mine workings within an inch or two of a vein show as a rule no alteration that can be ascribed to the vein solutions. They may be slightly turbid near their surfaces and along cleavage planes, but the same turbidity is visible in specimens collected from most parts of the district. Many thin sections show vein quartz in actual contact with feldspar phenocrysts that are almost wholly fresh. In a few specimens of rhyolite collected from the 300-foot level of the Montgomery-Shoshone mine the microscope shows that some calcite has developed in the rock by replacement of orthoclase and plagioclase phenocrysts and of parts of the groundmass. Sericite is rare, even in the rhyolite fragments in the veins.

At the Original Bullfrog mine the rather heterogeneous and in part thin-layered flow breccias making up rhyolites No. 1 and No. 2 are more thoroughly altered by vein-forming agencies than are the rocks exposed in the other mines. The shattered material has been actively replaced by both quartz and calcite. Even here, however, the chemical action of the vein solutions appears to have been confined to the fractured portions of the rhyolite and there is no extensive alteration of the country rock. Specimens taken from the transition zone between the vein and the hanging-wall rhyolite, that, under the microscope, show extensive enlargement of the quartz phenocrysts by vein quartz and complete recrystallization of the groundmass into a quartz mosaic, still retain some unaltered phenocrysts of feldspar.

On the whole the chemical activity of the ore-depositing solutions has been comparatively slight, being confined to the deposition of quartz and calcite with a little pyrite and associated gold and silver in and immediately adjacent to fissures. A large number of the fissures, it should be remembered, show practically no vein deposition. Results so slight suggest that the vein solutions were dilute, cool, and under no heavy pressure.

GENESIS OF THE DEPOSITS.

It should be clear from the foregoing description that the Bullfrog district, in its present stage of mining development, is not likely to contribute greatly to the rather meager knowledge of how ore deposits are formed. Nevertheless the work has not been wholly fruitless of suggestion and has led to one or two inferences that may have some value.

Any consideration of the genesis of the ores reverts to the origin of the faults, concerning which Messrs. Emmons and Garrey have concluded that they are normal and that in general the horizontal component of the movement, although large, was less than the vertical component. They have confined their discussion to the description of facts and to an interpretation of the mechanics of the faulting and have conservatively refrained from suggesting even a proximate cause for the elaborate dislocation that is the most interesting structural feature of the district.

As pointed out on page 16 and shown in Plate I, the volcanic series of the Bullfrog Hills is bounded on the south by a fault or zone of faults that separates it from the pre-Tertiary rocks. These older rocks are exposed only in the southwest and southeast corners of the district, but they have been found at a depth of 300 feet under the town of Bullfrog and probably continue beneath the wash along the entire south edge of the area mapped. On the west the Original Bullfrog fault has a general dip of about 18° N. On the east the dip of the Amargosa fault is not known, but it also appears to be low. The relations to each other of the rocks on opposite sides of these fault planes are those generally considered as indicative of normal faulting. If these are normal faults the pre-Tertiary rocks south of them presumably were covered at one time with the entire volcanic series, over 6,000 feet in thickness, and have since been laid bare by erosion during Quaternary or late Tertiary and Quaternary time.

There are difficulties in the way of this supposition. Bare Mounttain, whose summit, 6 miles southeast of Beatty, attains an elevation of over 6,200 feet above sea level, is composed of pre-Tertiary rocks upon which there are no remnants of the Tertiary lavas south of the eastward continuation of the fault zone. The mountain appears never to have been covered by the volcanic series. The dip of the fault is certainly too low to have permitted the material on the hanging-wall side to slide down by gravity alone. If it moved in this direction at all it must have been pushed down by material set in motion from the south on a part of the fault fissure steeper than that now visible. All of this impelling mass of volcanic rocks, if it ever existed, has been wholly removed.

Another hypothesis is that the volcanic rocks were poured out in a basin that extended far to the north of the Bullfrog district[a] and was bounded on the south by hills of pre-Tertiary rocks; that the entire mass of volcanic material was subsequently crowded against these older rocks and was thrust over them for an unknown distance along the Original Bullfrog and Amargosa faults. In other words, the foot wall of these fissures may be in part an old topographic surface.

An extensive thrust movement of the kind suggested is not incompatible with normal faulting of the rocks in the hanging wall, even under the supposition that normal faulting is always due to settling after the failure of an underlying support. When a mass of rock overrides an uneven surface it must adjust itself to the inequalities of that surface unless its rigidity is so great that the mass is competent to support its own weight over the depressions in the foot wall and can rest without deformation on only a few protuberances. In general the rocks in the hanging wall will be competent (to use the expressive term introduced by Willis) only over small inequalities and will collapse over large ones, either during the thrust or when the compression relaxes. Such collapse will take place by flexure and flowage or by fracture and faulting according to circumstances. Slight settling, soft, thinly laminated rocks, and heavy load will favor flexure and flowage; extensive settling, brittle massive rocks, and light load will favor normal faulting. Two of the conditions favorable to faulting, namely, brittle rocks and light load, were undoubtedly present when the rocks of the district underwent deformation. The third condition, irregularity of foot wall, is indicated by the exposures along the Original Bullfrog and Amargosa faults and accords better with the hypothesis of overthrust over a prevolcanic topography than with the supposition of normal faulting along a fissure that cuts across the rock formations irrespective of older contacts.

Of the two hypotheses discussed, the second, that of overthrust, appears to have most in its favor. Proof, however, is not obtainable and it is doubtful whether mine workings in the northern part of the district will ever be carried deep enough to decide this question. Should a shaft at any time show that the Original Bullfrog and Amargosa fault zone continues under the northern part of the district with a low dip and with pre-Tertiary rocks in the foot wall, the second hypothesis will be supported by much more substantial evidence than can now be adduced for it.

Whichever hypothesis may be true, it is probable that the volcanic series as a whole rests on Paleozoic or older rocks, comprising limestone, shale, and schist, and that the contact is a surface of

[a] See Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: Bull. U. S. Geol. Survey No. 308, 1907, Pl. I.

faulting. It is probable also that most of the normal faults that cut the lavas do not extend below this contact, although some of the more extensive dislocations presumably do so. The fact that a fault fissure is occupied by a basalt dike does not prove that it itself extends to profound depths. The magma may have come up through other channels and have found its way into the fault fissure comparatively near the surface.

One of the most interesting features of the veins in view of the siliceous character of their walls is the abundance of calcite they contain. This mineral has clearly not been derived from the rhyolites, for these would have to be extensively leached and altered over wide areas to furnish so large a supply of calcite from rocks originally so deficient in calcium; whereas, as has been shown, the rhyolite near the veins is fresh, or shows the introduction of calcite. Nor do the basalt flows and dikes appear to have supplied the calcite to the veins; for these have undergone only the ordinary decomposition due to weathering, in which the calcium of the silicates, changed to the carbonate form, remains in the rock, in part as the filling of vesicles. There is apparently no significant relationship between abundance of calcite in the veins and the proximity of basalt. The veins in the Montgomery-Shoshone mine, for example, become more calcitic with increasing distance from the basalt in the main fault zone. It is probable that the calcite in the veins was derived from the Paleozoic limestone, which without much doubt underlies the volcanic series over a considerable part of the area studied. It follows that the solutions by which the ores were deposited ascended from the pre-Tertiary rocks.

It does not appear possible to connect the ores genetically with any particular one of the many magmas that solidified as the lavas now exposed in the district. Their deposition may have closely followed the intrusion of the basalt dikes, but this sequence would perhaps have more significance were it not that basalt was erupted several times during the volcanic history of the region and were it known that the dikes are younger than the quartz basalt, dacite, and some of the later rhyolites, which are not, so far as known, cut by basaltic intrusions.

As already pointed out, the solutions that deposited the ores were neither hot nor concentrated and evidences of solfataric action are wanting. They contained, in combined or ionized condition, calcium bicarbonate, silica, disulphide of iron, manganese, silver, gold, and in some places a little copper.

The comparative recency of the lavas, the lack of any evidence to suggest that they have ever been deeply buried under still younger formations, and the character of the faulting all indicate that the parts of the veins now visible were formed within a few hundred feet of the surface. At the most, the overlying rock probably did not exceed 3,000 feet in thickness.

FUTURE OF THE DISTRICT.

It must be admitted that the sanguine expectations aroused by the discovery of the rich oxidized ore of the Montgomery-Shoshone mine in 1905 have not been realized. No other bodies of equal size and richness have been found and it is now known that even this mass does not maintain its high tenor to great depth. Other oxidized deposits, although they have proved to contain small bunches of rich ore, are as a whole of too low grade to ship, and few of them have been shown to possess such size as would warrant the installation of mills capable of treating them profitably on a large scale. The character of the ore below the zone of oxidation is still problematic. The chances are, however, that little of it will average over $10 a ton.

On the whole, the deposits in the Bullfrog district, unlike those at Goldfield, are not likely to yield quick and large profits with a moderate outlay of capital, although small masses of superficial ore may for some time reward a few fortunate lessees.

The question whether the sulphide ores can be successfully mined under present conditions in this region will undoubtedly soon be answered by the experience of the Montgomery-Shoshone company. The likelihood of others succeeding if this mine can not be worked below the zone of oxidation is small. It is certain that unless the sulphide ores are so abundant as to justify extensive and economical operations the district has little promise. The chances for such abundance would be greater were there more indications of strong chemical action by ore-bearing solutions than are to be found in the rocks now visible.

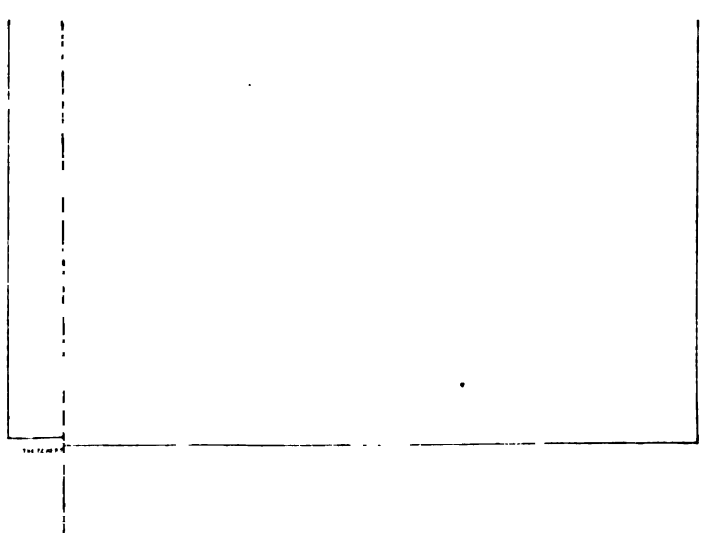
DESCRIPTIONS OF INDIVIDUAL MINES.

MONTGOMERY-SHOSHONE MINE.

INTRODUCTORY STATEMENT.

The Montgomery-Shoshone Consolidated Mining Company, with offices in New York, owns most of the issued stock of the Montgomery-Shoshone Mines Company, the Shoshone-Polaris Mining Company, and the Crystal-Bullfrog Mining Company. The property comprises fourteen contiguous claims, covering in all about 178 acres. The consolidation includes also the Bullfrog Reduction and Water Company and the Goss and Davis ranches, north of Beatty, with their water rights.

By the end of the year 1905 the Montgomery-Shoshone mine had been developed to a depth of 150 feet and a large body of rich silver-gold ore had been blocked out. The property at this time was in litigation and no large production had been made. The present consolidation was effected early in 1906, and a report made by the president to the stockholders in November, 1907, estimated the



total value of ore blocked out and on the dump at $5,000,000. Mr. Henry Krumb's report, made in March, 1908, gave the probable operating profit of the mine as about $400,000. The Montgomery-Shoshone, when visited in 1908, was 600 feet deep, with about 9,000 linear feet of drifts and crosscuts. The mill, which was constructed to have a daily capacity of 300 tons, is limited by the slow percolation of the cyanide solution to about 160 tons a day of ore averaging from $10 to $15 a ton. It is equipped with a jaw crusher and three sets of rolls. The pulp, carried in weak cyanide solution, passes to classifiers, whence the sands go over Wilfley tables and the slimes over vanners. There are no amalgamating plates. The Wilfley tailings are cyanided by percolation and the vanner tailings by agitation. The percentage of extraction was not ascertained, but is known to be rather unsatisfactory; the slimes are particularly troublesome and require the addition of considerable lime to neutralize the sulphuric acid present.

A microscopical examination of a sample of Wilfley concentrates, which yielded on assay 16.78 ounces of gold and 278.06 ounces of silver to the ton, showed that about half the material is quartz. With this are pyrite, particles of limonite, little pellets of a soft yellowish kaolin-like material, and a little cerargyrite. No gold could be seen.

UNDERGROUND DEVELOPMENT.

A general plan of the underground workings of the Montgomery-Shoshone mine is shown in Plate XIII. The old 100-foot level is at the same elevation as the collar of the new shaft and the levels below this are all about 100 feet nearer the surface than their names indicate. Thus the level at the bottom of the 600-foot shaft is called the 700-foot level. The position of the main ore body is indicated by the close tangle of drifts and crosscuts a hundred feet southeast of the main shaft. The drifts running south-southwest from this ore body follow the two main branches of the Montgomery-Shoshone vein zone, which apparently coalesce about 500 feet south of the shaft. The drifts running southwest from the vicinity of the main shaft to the Polaris shaft are in general parallel with the Montgomery-Shoshone fault and lie on the southeast side of the basalt strip that occupies part of the fault zone. The nearly north-south drifts near the Polaris shaft are on the Polaris vein. At the time of visit, in July, 1908, no stopes had been opened below the 400-foot level and the 700-foot level comprised merely the shaft station. The drifts and stopes above the 200-foot level had in part been obliterated in the formation of an open pit or "glory hole" (see Pl. X, *A*) and in part obstructed by the caving of the unsupported walls of this irregular opening. A portion also of the 200-foot level directly under the large stope had been crushed in by the weight of loose rock and ore and could not be examined in 1908.

GEOLOGIC FEATURES.

The general country rock of the workings, at least on the upper levels, is rhyolite No. 10. This is separated from rhyolite No. 16, northwest of the mine, by the Montgomery-Shoshone fault zone and by a dikelike strip of basalt along this zone. This basaltic strip was supposed at the time the general geologic mapping was done to be a dike, although it was recognized that the partly amygdaloidal character of the material was suggestive of a narrow down-faulted portion of a flow. At that time the linear and fairly persistent exposures of the rock and the fact that other similar masses are clearly dikes were held to overweigh the alternative suggestion. Later developments in the Montgomery-Shoshone mine have shown beyond reasonable question that the basalt is not a dike, but is a slender prismatic block of extrusive material bounded on two sides by faults and resting on rhyolite No. 10.

The general relations of the basalt to the rhyolite and to the veins may be best understood by reference to the geologic plans of the mine levels and the section shown in Plate XIV. At the surface the basalt is not very satisfactorily exposed. Being decomposed and soft, it has no prominent outcrops, and it is partly concealed by rhyolitic detritus. On the 100-foot level it is cut in the original Montgomery-Shoshone and Polaris adits, as shown in Plate XIV. On the 200-foot level the basalt is known to be nearly 200 feet wide near the main shaft; its northwest side had not been reached at the time of visit. Near the Polaris shaft it is narrower, the width here being probably less than 25 feet. Near the 300-foot level the main shaft, at a depth of about 200 feet, unexpectedly went through the bottom of the supposed dike into rhyolite that appears to belong to flow No. 10. (See Pl. XIV.) At the station on this level the bottom of the basalt is a curved, irregular surface, which dips in general to the northeast and is accompanied by some gouge. A narrow strip of basalt appears to continue southwest past the Polaris shaft, as shown on the plan of this level. On the 400-foot level a northwest crosscut near the main shaft, about 250 feet in length, is all in rhyolite. A little basalt is exposed in the northwest side of a drift about 150 feet northeast of the shaft, and some masses are known north of the Polaris shaft. The 500-foot, 600-foot, and 700-foot levels are all in rhyolite.

The mine workings, as is evident from Plate XIV, throw very little light on the northwest contact of the basalt, which is probably the plane along which most of the movement of the Montgomery-Shoshone fault zone has taken place. (See description of the Providence mine on p. 111.) The crosscuts northwest of the main shaft on the 200-foot and 400-foot levels would probably cut this branch

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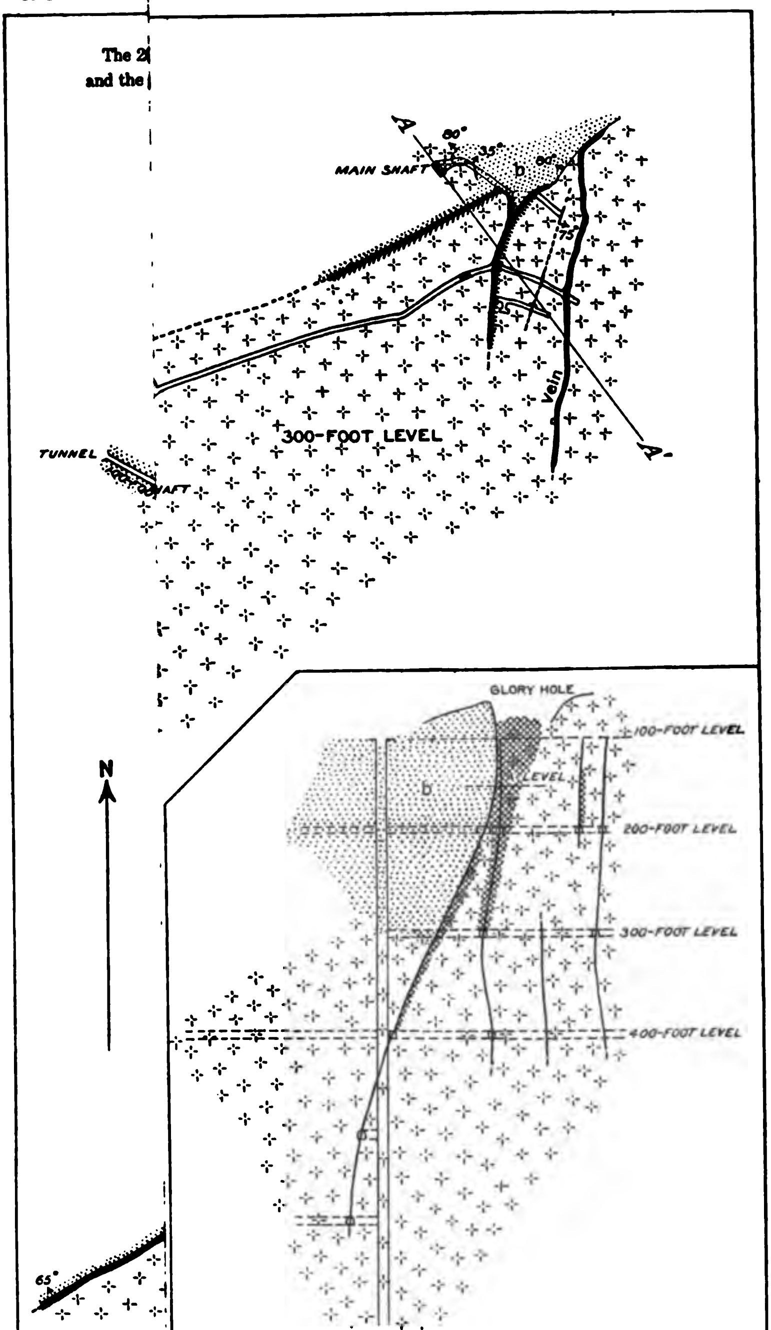

VERTICAL SECTION THROUGH A–A′

of the fault if extended a little farther. The fissure that bounds the basalt on the southeast and that continues below this rock into the rhyolite (see Pl. XIV) is in part ore bearing and has been much better explored. As a rule the basalt and rhyolite are separated by a thin sheet of gouge, which would not ordinarily be taken as indicating more than slight movement of one rock past the other. In some places this seam of gouge is not thicker than a sheet of stout cardboard, yet, as shown by the cross section (Pl. XIV), the minimum displacement along this one fissure can not be less than 200 feet. Moreover, southeast of the main shaft, on the 200-foot level, the contact surfaces of the two rocks show deep, rounded corrugations with parallel striæ, all of which pitch about 10° E. This shows that the latest movement along the fault zone at this place was nearly horizontal and that the total displacement therefore was considerably greater than the 200 feet required on the supposition of movement in vertical planes alone.

The basalt is generally more or less decomposed, and much of it is traversed by many irregular curved fissures with slickensided walls. It has undergone much internal movement, and this fact and the resulting plasticity of the mass as a whole accounts in great part for the absence of conspicuous brecciation of the rhyolite in contact with it. In the progress of faulting the comparatively soft basalt, with its innumerable fractures and polished slipping surfaces, was able to adjust itself readily to change of form and to slide smoothly over inequalities in the rhyolite walls without shattering them to fault breccia.

Petrographically, the basalt is an ordinary feldspathic, olivinitic variety, in which few of the mineral constituents are visible to the naked eye. The most compact and freshest specimens collected underground show under the microscope small porphyritic crystals of augite and olivine, the latter almost wholly altered to serpentine, in a microlitic groundmass consisting chiefly of plagioclase, augite, magnetite, and a large proportion of glass. The small crystals are arranged so that the longer axes of most of them approach parallelism, and they sweep in curved trains around the larger crystals in the manner characteristic of lavas that have congealed rapidly as flows in contradistinction to magmas that have consolidated more slowly as dikes. The abundance of glass suggests also that we have here to do with an extrusive and not an intrusive rock. Additional evidence for the same conclusion is presented at the bottom of the basaltic mass where it is penetrated by the main shaft on the 300-foot level. The basalt at this place is a dull, reddish, earthy-looking rock, with lighter mottling. It is clearly much decomposed and contains a large proportion of calcite. The microscope shows that the material was originally a very spongy or scoriaceous glassy

basalt and that the mottled appearance is due to the filling of the irregular vesicular cavities with impure calcite. This variety represents the frothy lower part of a lava flow that once spread over a surface composed of rhyolite No. 10. Similar mottled basalt is exposed northeast of the shaft on the 400-foot level, where, also, it probably indicates proximity to the base of the flow. An amygdaloidal facies was noted also by Mr. Emmons in the excavation for the mine boarding house. It thus appears that the basalt of the Montgomery-Shoshone mine is a down-faulted portion of plagioclase basalt No. 4, which is a flow overlying rhyolite No. 10 and is extensively exposed between Montgomery Mountain and Beatty. (See Pl. I.)

There are some notable irregularities of the southeast contact of the basalt with rhyolite No. 10 in the Montgomery-Shoshone mine, particularly on the 200-foot and 300-foot levels, southeast of the shaft. (See Pl. XIV.) These are due to displacement of the main fault contact by minor slips, which appear to be connected with movements along the veins in the rhyolite.

The total thickness of rhyolite No. 10, according to Messrs. Emmons and Garrey, is about 400 feet. At many places in the district it has a distinct glassy facies at its base, which serves to mark the division between it and the underlying rhyolite No. 9, which is about 250 feet thick. It thus appears that the Montgomery-Shoshone workings, with a depth of 600 feet, should go through rhyolite No. 10 into rhyolite No. 9. I have been unable to detect this change underground. The specimens of rhyolite from levels below the 300-foot are slightly more porphyritic than those collected above, but the microscope shows no essential difference in the rocks. As stated by Messrs. Emmons and Garrey, on page 45, certain varieties of rhyolite No. 9 are very similar to rhyolite No. 10, and where the base of No. 10 is not glassy positive distinction between the two rocks is probably not possible in ordinary underground exposures. If a continuous vertical section, such as that afforded by the main shaft during sinking and before timbering, could be carefully examined and specimens collected at intervals, it might be possible to determine the contact between the two flows. The present levels and accessible stopes, however, are not adequate for this purpose. The rhyolite exposed in them is practically and lithologically uniform and presents only such color variations as are due to changes connected with mineralization and weathering.

VEINS.

The veins worked in the Montgomery-Shoshone mine are filled fissures in rhyolite. As a rule, the fissuring is rather irregular with a tendency toward sheeting and brecciation. Consequently, most of the

veins contain many fragments of rhyolite embedded in the materials deposited from solution. The walls in general are rough and indefinite and there has not been much slipping along them since the veins were formed. The general plan of the veins is apparent from Plate XIV. In the neighborhood of the main shaft is what may conveniently be designated the Montgomery-Shoshone vein zone. This has a course ranging from north to northeast and as a whole is practically vertical. There are two main branches in this zone, which converge southward and which inclose between their northern portions numerous less persistent fissures. On the north they terminate against the basalt. On the 100-foot and A levels the rhyolite between the two main branches of the veins for distances ranging from 50 to 150 feet south of the basalt was all irregularly fissured and constituted the large body of rich oxidized ore worked in 1906 and 1907, of which only the outer shell now remains. A large proportion of this ore was a soft crumbling mass, consisting largely of kaolinite irregularly streaked with stains of iron oxide. Within this soft material could be detected residual fragments of less-altered rhyolite, loose quartz phenocrysts, and small anastomosing veinlets of quartz. Native gold and cerargyrite were both visible in the best ore. The whole clearly represented the alteration, within the belt of weathering, of a mass of thoroughly shattered rhyolite which had been veined and cemented by quartz. This ore was said to carry as much as $700 per ton, nearly half of the value being in silver. According to Mr. Ralph I. Johnson, who assayed much of the Montgomery-Shoshone ore for the original owners, the average ratio of gold to silver in 160 samples was 1 ounce of gold to 25.44 ounces of silver. This ratio suggests much secondary concentration within the zone of oxidation. At the present time the 100-foot and A levels are not used; and since much of the structure has been obliterated by stoping and caving, it has not been practicable to trace the veins up to the basalt, as has been done on the 200-foot and 300-foot levels shown in Plate XIV. As may be seen on the 400-foot level, the veins in some places are deflected at the basalt and continue for some distance along its contact.

The same vein zone appears on the 400-foot level, but the veins are smaller and are of too low grade (under $5 a ton) to work. On the 500-foot level this zone has not been explored and on the 600-foot level the veins, so far as opened in 1908, are narrow, of no value, and apparently less persistent than on the levels above.

The Polaris vein lies from 300 to 500 feet west of the zone just described and has been explored for a length of about 400 feet on the 200-foot and 300-foot levels. As shown in Plate XIV, its course is curved and varies from north to north-northwest. It dips 60° W. Like the veins east of it, the Polaris ends abruptly at the basalt.

Another important vein is one that may be designated the contact vein, since it follows the contact between the basalt and the rhyolite. On the 200-foot and higher levels the contact shows very little vein material. On the 300-foot level, however, the rhyolite alongside the basalt in the vicinity of the main shaft has been fissured and mineralized to a width of 4 to 6 feet and has been stoped for a distance of about 160 feet along the level and nearly up to the level above. A stope on the same ore body, from 40 to 60 feet long, extends down to the 400-foot level, where the vein is only in part accompanied by basalt. On this level, also, there is another stope on the same vein east of the main shaft. The contact vein is not continuous all along the contact and in many places contracts to one or more close fissures. Some of the widest and best parts of the vein are at places where minor north-south fissures end at the basalt, as may be well seen on the 400-foot level west of the Polaris vein. On the 500-foot and 600-foot levels the contact vein is wholly below the basalt. There were no stopes on these levels in 1908 and none of the material exposed in the drifts was ore.

The primary filling of all the veins was mineralogically similar, consisting of quartz, calcite, and comparatively small quantities of pyrite. The precious metals were probably originally contained in the pyrite, although it is possible that other sulphides were present also. The quartz and calcite appear to have been irregularly intercrystallized, partly as the filling of simple open fissures and partly in zones of shattered rhyolite where the filling served as the cement for a loose breccia. In general, the veins were originally most siliceous near the basalt and became more calcareous toward the south.

None of the vein material visible in the workings in 1908 retains its original character; it has all been modified by oxidation and solution. In the course of this alteration most of the pyrite has been changed to limonite, the gold has been set free, and the silver has combined with chlorine as cerargyrite. The resulting sulphuric acid, with the carbon dioxide introduced by percolating atmospheric water, has kaolinized the neighboring rhyolite and has helped to dissolve the calcite, leaving behind dark-brown or black mixtures of hydrous oxides of manganese and iron. During the process some silica has gone into solution and has formed fragile, lamellar pseudomorphs after calcite of the kind described on page 94. There is some question, however, whether this pseudomorphic replacement is altogether the work of oxidizing solutions. The structure is found in some of the veins on the 600-foot level, where the quantity of quartz deposited in and around the pseudomorphic skeletons is so abundant as to suggest rather more active transportation of silica than is usually credited to cold descending water. Unfortunately the work-

ings were not deep enough in 1908 to afford a conclusive answer to this question. However deposited, this later quartz appears to contain no pyrite and no gold or silver. This, so far as it goes, is suggestive of deposition by water from the surface.

The veins of the Montgomery-Shoshone zone and the Polaris vein, particularly those parts distant 200 feet or more from the basalt, are composed of dark, friable, cavernous material, which is largely pseudomorphous quartz and earthy manganese and iron oxides. Such vein matter is as a rule not ore. The only parts of the north-south veins that have proved profitable are within a distance of 150 feet from the basalt and are those portions in which the filling originally contained much more quartz than calcite. All the drifts on these veins when driven south beyond this distance show a decrease in the tenor of the material, accompanied by an increased prominence of those features that indicate a vein originally composed mainly of calcite. In this respect the long drifts to the south have proved uniformly disappointing. Assay plans of the principal levels are given in Krumb's report. The highest assay recorded by him was 27.45 ounces of gold and 426.2 ounces of silver, or $783.41 a ton. This sample came from the main ore body, 17 feet below the 100-foot level.

Oxidation of the veins extends to the 600-foot level but is not quite complete, as is shown by the presence of some pyrite in concentrates from the ore of the 400-foot level. Water was first found at a depth of 545 feet (45 feet below the 600-foot level) and for a time the shaft is reported to have made 30,000 gallons in twenty-four hours. About 20,000 gallons a day was pumped during the cutting of the 700-foot station. This level is expected to throw light on the size and value of the ore bodies below the zone of oxidation.

PROVIDENCE MINE.

The Providence is a prospect on the Montgomery-Shoshone fault zone, northeast of the Montgomery-Shoshone mine. No ore has been found, but the workings are of interest in connection with the fault and its associated strip of basalt. A geologic plan of the levels is shown in figure 18. The new shaft is about 870 feet northeast of the main shaft of the Montgomery-Shoshone mine and is in rhyolite No. 10. The shaft had been abandoned in 1908 and the 50-foot level was the only one examined. The crosscut northwest from the shaft goes through a foot or two of crushed and squeezed basalt into rhyolite No. 16, showing that the fault zone has at this point narrowed to practically a single fissure. In the drift northeast of this crosscut the two rhyolites are separated merely by a seam of gouge which dips 53° NW. West of the shaft the basalt widens to 30 feet and has gouge seams on both sides.

The old shaft, also abandoned, is 400 feet northeast of the n
It started in basalt but went through the foot wall of this into rh
lite No. 10. A curved crosscut northwest from the shaft exposes
section shown in figure 18. About 100 feet north of the shaft is w
appears to be a small basaltic dike, 4 feet wide, in rhyolite No.
This dips 50° NW. and appears to be generally parallel with the f
zone. It is not vesicular and the contacts are so close as to sup
the conclusion that this is not a fault slice but is intrusive.
main basalt strip is about 30 feet wide on this level. The rock, w
is all soft and decomposed, is partly vesicular and is full of cu

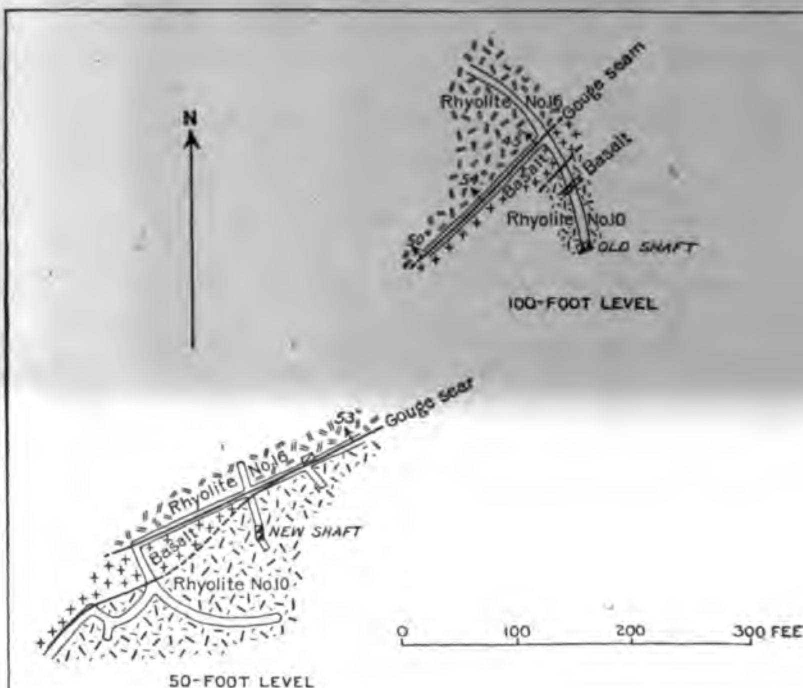

FIGURE 18.—Geologic plan of the Providence mine.

and polished surfaces of slipping, the basalt being squeezed in
lenticular fragments of all sizes up to 2 or 3 feet in diameter. T
hanging wall is remarkably smooth and consists of slickensid
rhyolite No. 16, with numerous grooves and striæ, which pitch 6
NE., showing that the last movement along the fault was m
nearly vertical than horizontal. The average dip of this wall
about 50°. The rhyolite of the hanging wall is very little disturb
and most of the movement of faulting was evidently concentrat
along the yielding basalt.

If the surveys from which figure 18 was compiled are accurate it
evident, even when the dip and the difference in depth of the t

levels is taken into consideration, that the strike of the Montgomery-Shoshone fault is far from being a straight line.

NATIONAL BANK MINE.

The National Bank is a prospect situated on the west side of Ladd Mountain, close to the town of Rhyolite. (See Pl. XI, *A*.) When first visited in January, 1906, the mine was operated through a vertical shaft 200 feet deep and had two short levels. No work was in progress in 1908 and the workings were not again examined.

As exposed at the surface and on the 100-foot level, the National Bank vein is a rather indefinite zone of fissuring in rhyolite No. 5. It strikes about N. 15° E. and dips west at 60°. The hanging wall is a basalt dike with an average width of 3 to 4 feet. The lode has no recognizable foot wall and consists of somewhat silicified rhyolite cut by many small and inconspicuous veinlets of quartz. The gold is not confined to the veinlets, but occurs also in the rhyolite, particularly where the latter shows little limonitic specks, representing oxidized pyrite crystals.

The ore is bunchy and good assays are sometimes obtained from the rhyolite at a distance of 30 or 40 feet from what is considered the main lode. The best assays obtained prior to the date of visit were about $230 a ton, mostly in gold. In the lower-grade ore the silver may exceed the gold, in one case there being about 5 ounces of silver to 3 of gold.

Considerable work has been done on the 200-foot level, mainly on a narrow seam which dips eastward at an angle of 45° to 50°, and which is probably the contact between two rhyolitic flows. The workings show that rhyolite No. 5 is, at this locality at least, made up of many layers or flows, some of which are only about an inch thick. These are separated by close regular partings that, as a rule, carry a little gouge and exhibit evidence of movement. The seam followed on the 200-foot level is such a plane of division between constituent parts of what is regarded as a single rhyolitic formation. The rhyolite below it is softer and a little more micaceous than that above, but is supposed to be a portion of rhyolite No. 5.

The dip of the National Bank lode from the surface to the 100-foot level would, if continued to the 200-foot level, carry the vein from 50 to 60 feet west of the shaft, or from 15 to 20 feet west of any crosscut in existence on this level at the time of visit.

A little ore has been shipped from near the surface but the mine has not been profitable.

GIBRALTAR MINE.

On the steep south slope of Bonanza Mountain is the Gibraltar mine, opened by three tunnels a few hundred feet in length. The

upper tunnel (No. 3) is on what is known as No. 4 vein, the one l
it (No. 2) is partly a crosscut and partly on the same vein, an
lowest (No. 1) tunnel is a crosscut. No. 1 tunnel enters the
slope of Bonanza Mountain only a few feet above the alluvium
2 tunnel is about 85 feet higher, and No. 3 about 60 feet above N
Six veins are recognized in the Gibraltar property. Their st
range from N. 15° W. to N. 20° E. and they dip to the west.
veins are numbered from east to west. No. 4, on which most
has been done, strikes about N. 10° W. and dips west at angles v
ing from 45° to 55°. No. 2 vein is the most nearly vertical, its d
the surface being about 80°. The croppings of the veins are sp
at various distances apart, ranging from 50 to 150 feet.

The general country rock of the mine is a rhyolitic flow bre
containing occasional inclusions of basalt up to 3 feet in diam
It has been correlated with rhyolite No. 6, though the many faul
Bonanza Mountain render the interpretation of the structure
satisfactory than in other parts of the district. The rock is co
erably altered and contains much secondary quartz.

The veins are small and occupy fault fissures of slight throw.
No. 4, which has been opened by two tunnels and has supplie
the ore so far found, is in most places less than a foot wide, altho
locally it widens to 3 or 4 feet. It consists of quartz and a
dark, earthy material, which is in part oxide of manganese. A
ernous and platy structure, due to the solution of carbonates fron
originally banded vein, is common. The best ore lies near the
wall and usually includes a little of the rhyolite. The gold, which
tains so much silver as to constitute electrum, occurs in the m
characteristic of the district, usually in little limonitic specks
quartz or silicified rhyolite. These rusty specks in rare insta
show small residual grains of pyrite.

The veins in general cut two older structures in the rhyolite.
of these is a set of planes dipping east at angles ranging from 30
35° parallel to the flow bands in the rhyolite. These may be parti
between separate flows or may possibly be cracks formed by
cooling of the rhyolite. The other structure is a fairly regular sh
ing striking N. 30° W. and dipping southwest at an angle of 6
When the lode fissures were formed they appear to have occasion
followed one or the other of these earlier fissures for short distan
so that the lodes are unusually crooked, as may be well seen in N
tunnel on No. 4 vein.

The Gibraltar mine has been an intermittent producer of ha
sorted shipping ore obtained from small bunchy pay shoots.
work was in progress during the second visit to the district in 190

TRAMPS MINE.

UNDERGROUND WORKINGS.

A general plan of the principal underground workings of the Tramps mine is shown in figure 19. The Hobo inclined shaft is in the saddle of Bonanza Mountain, through which passes the trail from Rhyolite to the Denver mine. The Tramp tunnel enters the mountain at its south end and the other shafts and tunnels are on the west slope. There are no stopes and all the work, which has an extreme vertical range of about 500 feet, is exploratory.

The portal of the Tramp tunnel is at an elevation of about 3,740 feet, just below the track of the Las Vegas and Tonopah Railroad. About 200 feet from the portal the tunnel cuts obliquely a small vein, and a crosscut at this point connects with the Nelson shaft and with a curved drift on the Nelson vein. Another vein has been drifted on about 400 feet farther north. Thence the tunnel turns northwest to the Eclipse vein, which it follows for a little over 100 feet to a raise of 106 feet up to the level of the Eclipse tunnel. A short west crosscut from the head of this raise reaches the Eclipse vein again, which has been drifted on for over 800 feet, past the Tramp and Eclipse shafts. Near the latter shaft, which does not, however, extend down to the Eclipse tunnel, an east crosscut of 140 feet reaches the Hobo vein at a point 167 feet below the workings on the same vein in the Manganese tunnel and Hobo shaft. The Eclipse tunnel follows the unimportant Tiger vein for about 150 feet from the portal and then turns as an oblique crosscut toward the Eclipse shaft.

GEOLOGIC FEATURES.

As shown by the work of Messrs. Emmons and Garrey, the southern spur of Bonanza Mountain is minutely dissected by north-south to northwest-southeast faults of small throw. The top and much of the east slope of the mountain are occupied by rhyolites Nos. 6, 7, and 8, with the thin flow of basalt No. 2 between rhyolites Nos. 6 and 7. The four formations together are probably not over 200 feet thick at this place and, as shown in Plate I, they dip to the east at an angle not very different from the slope of the hill. The mass of the mountain and most of the western slope is composed of rhyolite No. 5, which is the prevailing rock in the workings of the Tramps mine. The Hobo shaft is partly in rhyolite No. 8 and the Tramp tunnel is for some distance from the portal in rhyolite No. 6. The different rhyolites are distinguishable only with much difficulty underground, especially where, as in this mine, many of the drifts follow thoroughly oxidized veins. It would perhaps be possible to determine the approximate position of some of the underground contacts with the help of numerous microscopical sections, but the present state of the workings appears

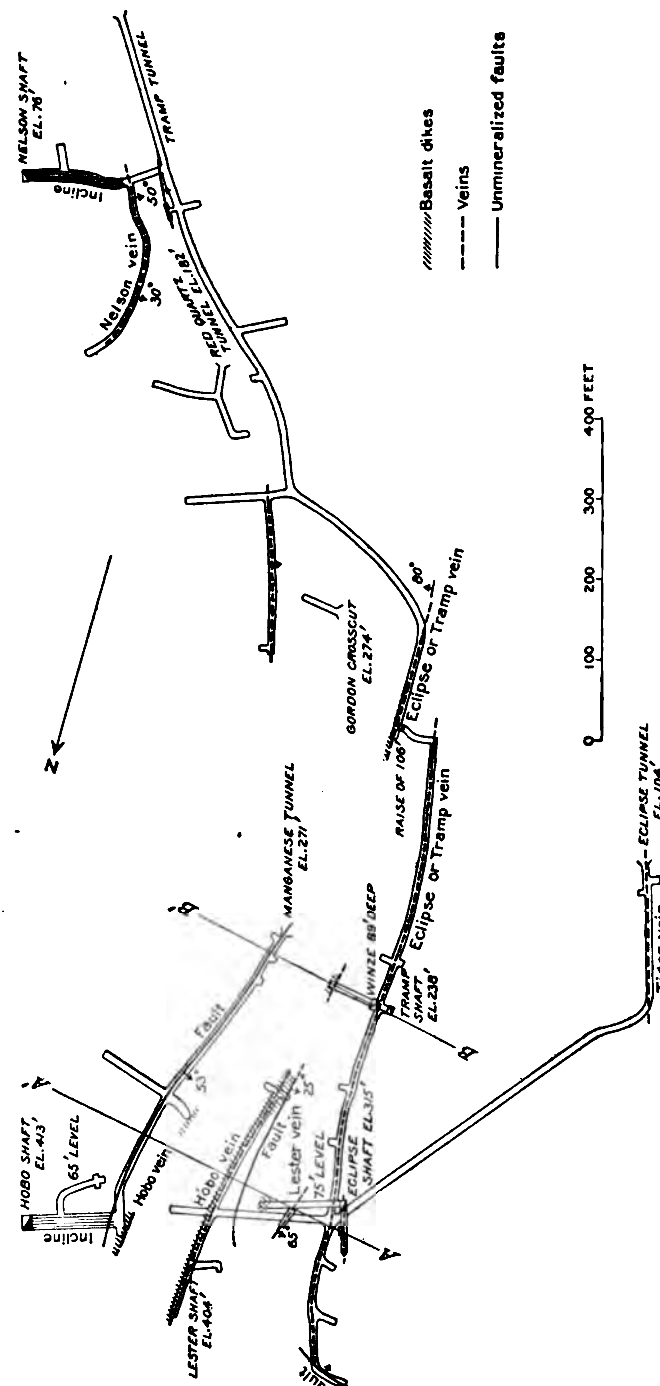

FIGURE 19.—General plan of the workings of the Tramps mine.

hardly to warrant the expenditure of time and labor that this would entail. There is no perceptible change in the veins at the passage from one rhyolite to another, and should the mine prove productive these superficial contacts will have no bearing on future development, which must be in rhyolite No. 5 and in underlying formations.

The only other rock found in the workings is basalt. This has the form of dikes, which run generally nearly north and south and which are as a rule accompanied by veins. The dikes vary considerably in width, the observed maximum being about 25 feet. The most regular and persistent is the one followed by the Hobo vein. The basalt is everywhere decomposed and in many places has been crushed and faulted by recent movement.

VEIN SYSTEM.

The vein system of the Tramps group is represented in slightly generalized form on Plate I, as the western half of the group of nearly north-south faults that cut Bonanza Mountain, the eastern half comprising the veins of the Gibraltar mine. At this place these faults are structurally unimportant, although the Scepter and Hobo faults are associated with increased displacement farther north. It is probable that none of the faults in the Tramps ground has a throw of over 100 feet and the displacement effected along most of them is certainly much less than this. The fissures shown on Plate I are not all mineralized and they represent the net result of movement at different periods, some prior to and some subsequent to ore deposition.

The veins as explored underground are shown in figure 19. The two principal ones are the Hobo and the Eclipse or Tramp vein. The Hobo vein outcrops at the collar of the Hobo shaft and can be traced down the steep hillside to the mouth of the Manganese (or Lester) tunnel. Thence the outcrop runs south, passes through the Gordon crosscut, and extends down the south slope of Bonanza Mountain west of the portal of the Tramp tunnel. The Eclipse vein outcrops along a line connecting the Eclipse and Tramp shafts. Although it can be traced for some distance south of the latter shaft its outcrop near the south end of the mountain is obscure and the vein is partly covered by detrital material. To the north the Eclipse fissure branches, one branch being the Saddle fault and the other the Scepter fault. (See p. 79.) The Hobo vein dips west at 53°; the Eclipse dips east at about 85°. Other veins, which are neither important nor persistent, are the Lester and Nelson, shown in figure 19. The Lester dips west at 65° and, as shown in figure 20, probably joins the Eclipse vein at a depth between 200 and 300 feet. The Nelson vein, as exposed on the Tramp tunnel level, near the Nelson shaft, dips west at 50° and is a fairly well defined streak of low-grade oxidized manganiferous material. As it is followed north the vein curves to the

east and becomes more nearly horizontal. Finally, at the end of drift, the fissure dies out in generally fractured rhyolite. The T vein, followed for about 150 feet in the Eclipse tunnel, is a ne vertical zone of fissuring in the rhyolite with no well-defined w It is not very persistent and although some good ore has been fo in it the quantity was too small to encourage further prospectin

A feature of much interest is a fault that appears in the cros between the Eclipse and Hobo veins in the Eclipse tunnel and short crosscut at the south end of the drift on the Hobo vein. fig. 19.) The fault fissure dips 25° W. and is filled with 1 to 2 of soft, crushed rhyolite. The same fissure is exposed at a poin feet below the Eclipse tunnel in a winze near the Tramp sh Here it cuts off the Eclipse vein, as shown in figure 20. From bottom of the winze, which is 89 feet deep, an east crosscut of 60

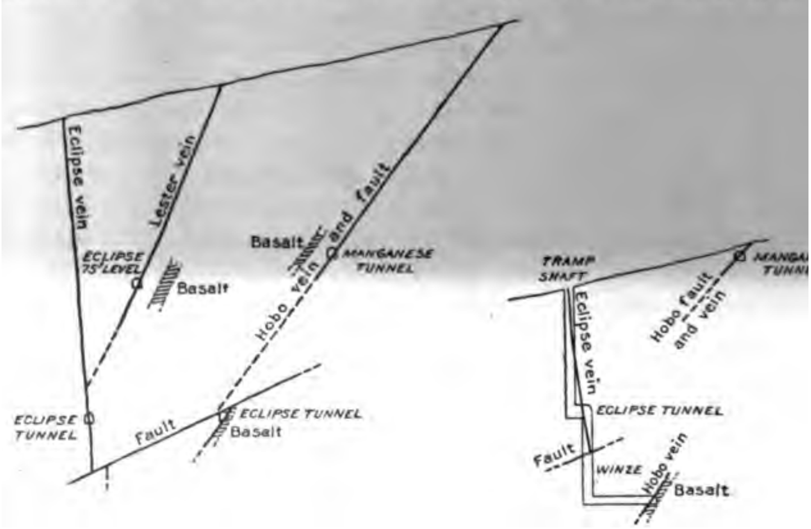

FIGURE 20.—Sections through the Tramps mine.

exposes a vein which is supposed to be the Hobo. This, howe is not certain and a glance at figure 20, where the known data plotted in cross section, shows that more development is necess before the hypothetical displacement, indicated by the dotted li may be accepted as a fact. The Hobo and Eclipse veins conve downward. What takes place where they come together is known. There has been postmineral movement along both fissu and it is yet to be ascertained whether, as seems more likely, final result of the movements has been the displacement of the Ecli by the Hobo, or vice versa.

The vein followed near the end of the Tramp tunnel is supposed those working the mine to be the Eclipse vein, and therefore

same as the vein opened in the Eclipse tunnel 106 feet above. It has the proper course and dip for this vein, but is about 35 feet east of its expected position on the Tramp level, as calculated from the average dip of the lode in the upper tunnel. The low-angle fault shown in figure 20 may pass through the connecting raise, which was not open at the time of visit, and so account for this discrepancy, the 35 feet being the measure of the horizontal separation at this place.

CHARACTER OF THE VEINS.

As the workings nowhere penetrate below the zone of oxidation the original character of the veins must be inferred from observations on weathered material. One of the best places for such study is the Gordon crosscut in the Hobo vein, on the west slope of the mountain, which exposes over 25 feet of vein material. The rhyolite was fissured to fully that width, the fracturing partaking in part of the nature of a sheeted zone but passing also into irregular rupture and brecciation. In the spaces thus provided were deposited quartz and calcite. The larger veinlets conform generally to the dip and strike of the lode as a whole, but the intervening plates of rhyolite are full of smaller stringers running in all directions. Many of these, particularly those in which calcite predominates, are regularly banded. This original structure of deposition is accentuated by partial weathering, which affects differently the various layers. The quartz is fine grained and much of it is almost porcelane in texture. It is, in part, irregularly crystallized, and in part interbanded with calcite. Both calcite and quartz, especially the latter, have to some extent replaced the fragments of rhyolite in the fissures. Such sulphides as may have been present in the parts of the Hobo vein exposed to view have mostly oxidized and it does not appear that they were ever abundant in the vein at this place. In richer portions of the vein a few minute crystals of pyrite can be detected in some of the hard residual fragments of quartz.

In the course of oxidation the calcite is attacked, calcium carbonate being removed and manganese oxide with silica being left behind. The vein becomes carious, the cavities being partly filled with sooty, impure wad, accompanied in places by the fragile skeletal pseudomorphs of silica after calcite described on page 94. In some of the banded veinlets the alteration to manganese oxide begins along certain planes of deposition so that the banding of the vein, as seen in section, is thereby accentuated by the presence of narrow, black parallel lines. As the weathering proceeds the coherence of the vein is destroyed and slight postmineral movements may transform the originally firm banded vein into a soft, structureless mass of stained quartz fragments mixed with dark, earthy hydrous oxides of iron and manganese and in some places coated with crusts of secondary calcite

crystals. In the richer parts of the vein the gold is partly in the soft, earthy material and partly in the cryptocrystalline quartz, as minute particles associated with small spots of rust that have resulted from the oxidation of crystals of pyrite. A very large part of the vein material in all of the lodes opened in the Tramps workings is of this soft, structureless character.

The Hobo vein generally accompanies a decomposed basalt dike, the dike being, as a rule, on the east or foot-wall side. In one place at least, however, on the Eclipse level, the Hobo vein is within the basalt. In other places some rhyolite intervenes between vein and dike. The vein is clearly younger than the dike and was deposited in fissures which followed in a general way the line of the dike without conforming accurately to either contact. The basalt does not appear to be continuous along the whole course of the Hobo vein and is found only here and there along the Eclipse vein. Other veins, such as the Tiger and Nelson, are not accompanied by basalt and some dikes cut in the workings are not accompanied by veins.

Both the Eclipse and Hobo veins have been affected by postdepositional movements within the plane of the lode. A good part of the displacement along the Hobo fault appears to be referable to this later movement, which has crushed both dike and vein (see Pl. XI, *B*) and produced a fissure not strictly nor continuously accordant with either.

Both the Hobo and Eclipse veins contain bunches of oxidized ore that will yield on assay over \$100 a ton, but these bodies are too small for profitable exploitation. There is probably a considerable quantity of ore ranging from \$20 to \$30 a ton in gross value, but this is not workable as the mine is at present equipped, although it could of course be profitably milled if there proves to be enough of this ore to warrant the construction of a mill. A very large part of the vein material in the present workings probably will not assay over \$10 a ton, which is probably too low for profit under the average conditions likely to prevail for some time in this district.

DENVER MINE.

The Denver mine, belonging to the Tramps Consolidated Company, is about one-third mile north-northwest of the workings described as the Tramps mine, on the Denver fault. (See Pl. I.) The country rock is rhyolite No. 5. The vein strikes generally north and south. For the first hundred feet in depth it dips about 70° E.; below it changes to the west, so that the vein as a whole is practically vertical. It is not, however, a single fissure, but is rather a narrow zone of fissures that depart from parallelism in strike and dip by small angles. The best bunches of ore occur here in one fissure, there in another.

The underground workings comprise four tunnels from 50 to 100 feet apart and a winze from the lowest tunnel connects with levels at

50, 200, and 300 feet below its collar. The combined depth of the workings is about 500 feet and the vein has been explored for a total length of 1,000 feet. Most of the levels, however, are much shorter than this, the bottom level being 350 feet in length.

The Denver claims were located in September, 1904, and the mine has been worked steadily on a small scale since that time, making shipments of hand-sorted ore from time to time. In July, 1908, stoping was in progress between the lowest tunnel and the 50-foot level of the winze. In other words, the stopes have been carried to a depth of 250 to 300 feet. Below this no shipping ore in stoping quantities has yet been found. The ore thus far extracted has all been oxidized and has occurred in comparatively small shoots, few of them having a continuous stope length of over 50 feet. The 300-foot level of the winze shows slight dampness and some pyrite, indicating that the bottom of the oxidized zone has practically been reached.

Prior to oxidation the Denver vein apparently consisted of quartz and calcite, carrying auriferous pyrite. This filling was in general less than a foot in width and appears nowhere to have exceeded 18 inches. As in most of the veins in the district, there was considerable sheeting and irregular fracturing of the brittle rhyolite and the fissures were partly filled with rock fragments before vein deposition began. The boundary between vein material and fissured and veined wall rock is not everywhere definite. In a few places, where the vein is distinct from its hard siliceous walls, these show strong slickensided corrugations, which in every case observed are more nearly horizontal than vertical. These are not mere gouge markings such as often record recent movement, but were channeled in the hard rhyolite under great pressure before the vein-forming solutions had completed their work.

In the course of oxidation the calcite, less abundant in this vein than in some others in the district, was dissolved or partly replaced by pseudomorphous silica and the usual sooty manganiferous residue left behind. The pyrite was changed to little specks of limonite in which are now embedded particles of native gold. As usual, the gold is more closely associated with the quartz than with the calcite, and the best ore is a fine-crystalline quartz consisting in part of small silicified fragments of rhyolite and being spotted with limonite. The limonite is partly in irregular stains or blotches and partly in distinct pseudomorphs after small crystals of pyrite. Small hackly particles of native gold are generally visible in these brown spots.

In a few places the vein is faulted by nearly horizontal fissures, the part of the vein above each fissure being displaced to the west. The greatest displacement observed is about 7 feet; and so far as is known the faulting, which is probably younger than the original ore deposition, has had no influence on the formation of the ore bodies.

ORIGINAL BULLFROG MINE.

The Original Bullfrog mine is 3 miles west of Rhyolite, at the south base of Bullfrog Mountain. The principal workings comprise a tunnel with several hundred feet of branching drifts and crosscuts and two shafts, one of which was 140 feet in depth in 1906. The only work in progress in 1908 was on a small scale by lessees, near the surface.

The Original Bullfrog lode outcrops more conspicuously than the other deposits in the district. It is a huge mass of nearly solid quartz which, as a whole, dips north at 18° to 20° and is at least 60 feet thick. The quartz is partly chalcedonic and banded and partly coarsely crystalline. Much of the latter variety is amethystine. The quartz rests in most places upon a much-sheared shaly material, greenish or reddish in color, which is so decomposed as to leave its original character in doubt. It is supposed to be a shale that belongs, with the underlying limestone, to the Paleozoic series. The shale is not of great thickness and in some places the quartz rests directly upon the limestone.

The lode has no definite hanging wall, but is overlain by rhyolite No. 2, which is fissured and contains stringers of quartz for some distance above the mass of the lode. The deposit represents a mass of rhyolite that has been greatly fissured and shattered. The fissures have been filled with quartz and with minor amounts of calcite and ore minerals; and to a considerable extent the shattered rhyolite has been completely silicified.

Some bunches of rich ore have been found, but the mass as a whole is of very low grade. The fissuring that provided opportunity for the deposition of so much silica was probably caused by movement along the Original Bullfrog fault (see Pl. I), which has here brought the rhyolites against the pre-Tertiary rocks.

The shipping ore consists of quartz that originally contained chalcocite, but the latter mineral has been nearly all changed to green, blue, and brown chrysocolla with a little malachite. Native gold occurs in visible particles embedded both in quartz and chrysocolla. There is generally some calcite with the ore and with the quartz throughout the vein.

BULLFROG WEST EXTENSION MINE.

The Bullfrog West Extension mine lies just west of the Original Bullfrog mine and is on the same large, nearly horizontal vein. The mine is opened by a vertical shaft with levels at approximately 115, 139, and 195 feet in depth.

The vein appears in general to have a slight dip to the north but is irregularly rolling. It rests partly on much-sheared and slickensided red shale and partly on limestone, both rocks having been

faulted before the rhyolitic eruptions and consequently before the vein was formed. The bottom level is entirely in these older rocks and is under the vein. The hanging wall is rhyolite No. 1 and the vein consists of a portion of this flow that has been shattered by movement along the Original Bullfrog fault and has been cemented and partly replaced by quartz.

The work at the time of visit in 1908 had been confined to exploration. It was reported by Mr. Leonard P. McGarry, the superintendent, that a considerable quantity of $50 to $60 ore had been blocked out, but that freight and treatment charges under conditions then prevailing amounted to about $35 a ton. The ore is similar to that of the Original Bullfrog in mineralogical character.

GOLD BAR MINE.

The Gold Bar mine is about 4 miles northwest of Rhyolite and is outside of the area covered by the detailed map (Pl. I) of the Bullfrog district. When it was visited in 1906 the main shaft, a 64° incline, was 150 feet deep and connected with several hundred feet of drifts on two levels. Mr. W. H. Emmons visited the mine in February, 1907, at which time new levels had been run at depths of 250 and 350 feet. His notes are made use of in the following description. About this time a 10-stamp mill was built, but the mine soon became financially involved and was idle in 1908.

The Gold Bar lode is a zone of irregularly fissured and brecciated rhyolite fully 100 feet wide. The hanging wall is generally a fairly regular and persistent slip along which some displacement has occurred since the vein was formed. On the foot-wall side there is no definite boundary between vein matter and more or less disturbed rhyolite. The general strike of the lode near the shaft varies from N. 55° E. to N. 65° E. and the average dip is about 65° NW. About 100 feet northeast of the shaft the fissure zone turns and runs due northeast for about 150 feet, beyond which it strikes nearly north toward the Homestake-King mine. The total length of the lode explored on the 150-foot level is about 1,000 feet. The other levels are much shorter.

In general the country rock of the mine is rhyolite, although some vesicular basalt appears on the two lower levels. This is probably part of an intercalated flow, but its relations are not clearly shown. The fissuring and shattering of the rhyolite and the fact that all of the workings are in oxidized ground render any study of detailed geologic relations unsatisfactory.

Although a little rich ore has been found, it is evident that the deposit is to be regarded as a large mass of low-grade material, such as can be worked, if at all, only on a considerable scale and by the most economical methods possible in this district. The rhyolite

has been greatly fissured along a wide zone and the fissures have been filled with quartz and calcite carrying some auriferous pyrite and perhaps free gold. The mass has been disturbed by subsequent movements; the vein material has oxidized to the usual products; and there has probably been some migration and reconcentration of the gold and silver into isolated bunches of richer ore.

HOMESTAKE-KING MINE.

The Homestake-King mine adjoins the Gold Bar on the north and is on the same lode. It is opened by a 63° inclined shaft 500 feet deep, with levels at 200, 300, 400, and 500 feet below the collar.

The vein is the northern continuation of the Gold Bar vein and is of the same general character. Considerable stoping has been done on a pay shoot over 100 feet in stope length and up to 40 feet in width. This extends from a point above the 200-foot level to the 400-foot level and pitches to the north. The ore, which is oxidized, shows no mineralization to the eye, but carries native gold and is tested by panning. No ore had been found on the 500-foot level at the date of visit in August, 1908. The deposit as a whole, like that of the Gold Bar, is of low grade.

A north drift on the 300-foot level, about 1,100 feet long, connects the main shaft with the King shaft, sunk to reach the same vein, but not now used. The Daisy, another abandoned shaft, about 1,100 feet northeast of the Homestake shaft, is on a nearly east-west fissure in rhyolite and is 200 feet deep.

The Homestake-King mine is equipped with a well-constructed 25-stamp mill, completed in the summer of 1908. The ore is treated by amalgamation and cyanidation, no concentration being attempted.

MAYFLOWER MINE.

The Mayflower mine is situated about 7 miles north of Rhyolite on a vein that strikes N. 50° W. and dips from 60° to 65° SW. The country rock is rhyolite, in part a flow breccia, and two or three flows appear to be exposed in the workings. The main shaft when first visited in 1906 was 100 feet deep. Mr. Emmons examined the mine again early in 1907 and found the main shaft 200 feet deep, with two additional shafts, the Combination and Starlight, on the same lode, northwest of the main shaft. His notes were used in connection with my own in preparing the following brief description. The property, after attracting a good deal of attention in 1907, was idle in 1908 and has never been productive.[a]

[a] There was some revival of activity in the vicinity of the Mayflower mine in 1909, the locality being known as the Pioneer district.

The lode is a zone of sheeting and shattering which averages from 4 to 5 feet in width. The hanging wall is generally regular and well defined, but the foot wall is less definite and the width of the vein in many places is not readily ascertained. It is claimed that the ore is in some places 40 feet wide. The fissures in the sheeted zone and the irregular fractures in the rhyolite of the foot wall were originally filled with quartz and calcite. This material has been oxidized to a depth greater than that reached in the shafts, and part of the calcite has been dissolved, leaving behind the usual manganiferous residue. Neither quartz nor calcite form solid veins but have been deposited rather as a cement to angular fragments of rhyolite and have in part replaced the smaller rock particles. The lode appears never to have contained much pyrite and as a rule the valuable constituents are not visible.

Mr. Emmons was informed that considerable bodies of ore averaged $20 a ton, but that the usual grade was from $8 to $12 a ton, nearly all of the value being in gold.

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